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The Devonian stratigraphy of Kerman, southeast central Iran.

The Devonian Stratigraphy of Kerman, Southeast Central Iran

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A thesis submitted to the University of Bristol in accordance with the requirements for the degree of Doctor of Philosophy in the Faculty of Science, Department of Geology.

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ABSTRACT

Devonian strata throughout Iran have similar stratigraphical characteristics, suggesting a relatively uniform depositional environment during this period. Sedimentary facies and fossils indicate a shallow water platform in north-northeast Iran, extending southward. Southwestern and eastern parts of Iran were uplifted by Caledonian epeirogenic movements. Lower Devonian fossils have not been reported but Middle and Upper Devonian strata contain mainly brachiopods and corals.

Devonian rocks outcrop over a wide area in northern Kerman. Red sandstones in Hutk and the conglomerate unit in Shams Abad are referred to the Lower and Middle Devonian respectively. Upper Devonian successions consist mainly of carbonates with minor clastics. The sediments contain brachiopods, corals, acritarchs and spores and range in thickness from 220 m to 480 m. Close correlation between the Upper Devonian strata in Kerman is indicated by these.

New brachiopod evidence suggests that the Frasnian/Famennian boundary be placed at the base of the shale bed (level 160 m), the base of the argillaceous limestone (level 195 m) and the base of the shale bed (level 190 m) in Gerik, Hutk and Shams Abad respectively.

1,831 brachiopods (31 taxa) collected in Kerman belong to taxa known elsewhere in Asia. Thirteen species fall into the Frasnian and eighteen belong to the known Famennian communities.

A 4-6 m thick coral mound is discovered west of Gerik village. 444 specimens of Rugosa and Tabulata have been obtained. Most of the corals are possibly in their growth location. A 30 to 40 cm thick coral bed is present within the Frasnian strata in the Hutk and Shams Abad sections. The external form of these corals indicates that the reef was formed in a moderately quiet environment.

29 spore and acritarch taxa are considered to be Frasnian in age. The palynomorphs indicate that Iran, the Arabian Peninsula and Western Australia were parts of the same biogeographic province during the Devonian period.

The Kerman conglomerate unit is referred to the Middle Devonian. The clasts are poorly sorted, submature and well rounded, suggesting a typical alluvial fan. Pebble orientation indicates that the source area may have been to the northeast of the province.

A model is proposed for the Zangu conglomerate, similar to Recent alluvial fan deposits in southern Arizona. The bulk of the unit was formed at a rate of about 48 cm/1000 years as a single alluvial fan in an arid to semi-arid region.

ACKNOWLEGEMENTS

This work, which is a contribution to the Devonian stratigraphy of Kerman province, southeast central Iran, was done under the supervision of Professor D. L. Dineley. It is a pleasure to acknowlege his advice and friendly encouragement which were fundamental during every phase of the work.

Some of the brachiopods were studied in the Palaeontological Department of the Natural History Museum, London, under the guidance of Dr. H. Brunton, to whom the writer is deeply indebted. Many thanks are due to Dr. M. G. Bassett of the National Museum of Wales, Cardiff, for his comments on the brachiopod descriptions.

The writer is also indebted to Dr. E. B. Selwood of the Geology Department, University of Exeter, for his suggestions and comments on the coral descriptions. Much appreciation is expressed to Dr. M. Ghavidel-Syooki of the National Iranian Oil Company, Tehran, for his assistance in the study of spores and acritarchs.

Thanks are also extended to Mr. S. Powell, Ms. C. Cheverton and to Mr. L. Neamat (Chairman of the Geological Survey of Kerman) for their assistance in producing the plates, typing the manuscript and providing a car for field work respectively.

Finally, I am most grateful to my wife F. Ferdowsi for her patience and encouragement throughout the period of this study.

Author's Declaration

I declare that the work contained in this thesis was my own except where it has been indicated.

Mohammad Dastanpour
14 December 1990
M. Dastanpour

MEMORANDUM

Extensive field work throughout the Kerman province reveals that the Devonian rocks have the greatest area of exposure of all the Palaeozoic systems in the area. The outcrops are easily accessible and are not far from the town of Kerman. In spite of their widespread exposure, literature and knowledge of the Devonian system in Kerman is small compared with that for the Devonian of northern Iran. Thus the study of the Devonian stratigraphy became an interesting subject to the candidate. In 1985, he visited several universities in the U.K. to discuss with geologists his interest in Devonian research. They all advocated application to the University of Bristol.

This research was officially begun in June 1987 and has continued to the present. During this period the candidate has spent about 23 months in Iran doing the required field work (nearly 5 months), laboratory processing (3 months) and the rest of the time has of necessity been allocated to full-time study and teaching at the University of Shahid Bahonar (Kerman). About 1750 m of the Devonian sections have been logged; 456 m of the conglomerate unit has been examined; 2575 individual brachiopods, corals and other fossils with about 300 rock samples have been collected.

The writer has had the privilege of having assistants to help during the course of field work, making thin sections and treating the samples for conodonts in Kerman. Some of the palynological processing has been carried out in the National Iranian Oil Company, Tehran.

Although Professor D. L. Dineley (supervisor of this research) has not been able to visit, the area of study was checked by Professor Kh. Khosrow-Tehrani of the Geological Department (University of Tehran) and Dr. M. Ghavidel-Syooki (National Iranian Oil Company). Thanks are extended to them for their assistance. Most of the rock samples, brachiopod and coral specimens together with photographs and slides have been lodged with the department in Bristol.

The expenses for this research were provided by the Ministry of Culture and Higher Education of the Islamic Republic of Iran. Appreciation is expressed to the head of the Scholarship Department. A period of three and a half years was granted to support the Ph.D. study, thus the research had to be completed within this length of time.

This submission takes the form of five separate but related reprints which, it is hoped, will form the basis of separate publications. It could also serve as the basis for further work on the Devonian stratigraphy in the Kerman region. The writer is also planning to continue his study on the stratigraphy of the Devonian in Kerman as well as in central Iran. His main interest is focused on the distribution, evolution and biostratigraphy of the brachiopods.

C.V. of Candidate

Date of Birth:	1945
Education:	High school and teacher training, Esfahan, 1960-1966. B.S. in Geology, University of Esfahan, 1969-1973. M.S. in Geology, Michigan State University, 1975-1977. Ph.D. in Geology (anticipated), Bristol University, 1987-1991.
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M. Dastanpour
14 December 1990

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Devonian stratigraphy of the Kerman province is important in a number of ways for palaeontological as well as geological purposes. The interest of necessity tends to centre about the Late Devonian because this particular interval is the one for which the record of Palaeozoic marine invertebrate faunas is almost complete. The stratigraphic evidence for the other Palaeozoic periods is less satisfactory because of the more limited outcrops, the presence of non-marine sediments, lack of fossils and/or the complete absence of data.

Devonian sedimentary rocks are exposed throughout the northern and northwestern Kerman region (Fig. 3.1). The Devonian strata in Kerman were originally mapped by Hückreide et al. (1962). Some years later, Dimitrijevic (1973) described the outcrops in the northwest and southwestern Kerman. Nevertheless, no detailed study of the Devonian System in this area has been published so far.

The purposes of the present research are as follows:

To review available literature on the Devonian System in Iran and to consider a possible correlation between the various outcrops. A palaeogeographic map of Iran during the Devonian will also be established.

Although many Devonian exposures in the Kerman province had been personally examined by the author, only five of the most prominent outcrops will be investigated in detail. The strata contain mainly brachiopods, corals and palynomorphs (spores and acritarchs) of the Upper Devonian. The Frasnian/Famennian boundary in the region may be tentatively identified.

Brachiopods constitute one of the commonest elements within the Upper Devonian faunas of the Kerman region. However, the published data on these fossils are remarkably limited and the existing records are fragmentary. This study has revealed that the Frasnian and Famennian brachiopods are abundant, diverse and taxonomically useful for correlation. They are described systematically below.

The Rugosa and Tabulata corals form a 4 to 6 m thick bed within the Frasnian successions in the Gerik section, 75 km north of Kerman town. In spite of their abundance, they have not been reported hitherto (see Chapter 5). Because of their rapid evolution the Rugosa are useful for local correlation and palaeoenvironmental interpretation.

Chapter 6 deals with the study of miospores and acritarchs. They are abundant within most outcrops in northern Kerman. Only the Nedenu section is barren of palynomorphs. The miospore and acritarch taxa provide information for confirming the referred age based on brachiopods and corals. These floras are also useful for correlation and palaeolatitude analysis.

A 20 to 56 m thick conglomerate unit forms the basal part of the Devonian strata in the Zangu Mountain, northwest Kerman. A purpose of this study is to determine the overall configuration of the unit, the source of the materials, the regional sedimentary environment and to propose a hypothetical model of the region. The conglomerate unit crops out along the Devonian section north of Shams Abad and extends for about 12 km to the north. The Zangu conglomerate was formed as a single alluvial fan deposit in an arid to semiarid region.

Conodonts are valuable fossils at all stages of geological analysis, from reconnaissance mapping to detailed correlation and zonation. Another aim of this research was to obtain conodonts in order to establish zonation and to identify the stratigraphical boundaries of the stages. About 60 samples were collected from five sections in the study area. Forty dark grey limestone samples were processed for conodonts using 10% acetic acid. The samples yielded only a few broken conodonts and fish teeth. The same processing technique was applied to the carbonate samples from the Devonian rocks of the Devonshire for a comparative study; many conodonts were extracted. Sedimentary environments with abundant corals, crinoids and brachiopods seem to be unfavorable for the association of conodonts (Brasier, 1980, p. 154). Because of the shallow and turbulent conditions of the environment in the Kerman region, the clastic rocks and the argillaceous limestones are poor in conodonts.

CHAPTER 2

DEVONIAN STRATIGRAPHY IN IRAN

2.1 INTRODUCTION

Geographically Iran lies between the old continental masses of Gondwana to the south and Eurasia to the north. Two mountain ranges bound the central Iranian Plateau: the Alborz (Elbourz) lies in the northern part, and the Zagros Mountain Range is on the southwest side of the plateau. The Zagros are part of an arc which extends from Kurdistan in northwest Iran as far southeast as the mountains of northwest India. These Iranian mountain ranges were formed during the Alpine orogenic movements. The central part of Iran is geomorphologically of plateau type throughout, although some parts are actually low and flat.

On the basis of tectonics, structural history and sedimentary facies, Iran is divided into nine geological zones (Stöcklin, 1966). Eftekhar-Nezhad (1981) recognized thirteen and Berberian and King (1981) considered six zones of structural and sedimentary basin development (Fig. 2.1). From a general point of view the Devonian rocks are exposed within the northern part of Iran along the Alborz Mountains, the Kopeh-dagh in the northeast and throughout the central region. Devonian sediments have not been observed in the Zagros Mountains. Sedimentary rocks yielding Devonian microfloras have been reported only in the Faraghan Mountains, 80 km north of Bandar Abbas (Ghavidel-Syooki, 1986).

Throughout much of Iran the Devonian strata lie conformably upon older Palaeozoic rocks and generally directly underlie the Carboniferous System, but universal conformity is unconfirmed.

Numerous publications have appeared on the geology of the Mesozoic and younger strata for the Zagros and Alborz Mountains but the Palaeozoic rocks, especially in the central and southeastern part of the country, are relatively unexplored compared with other regions.

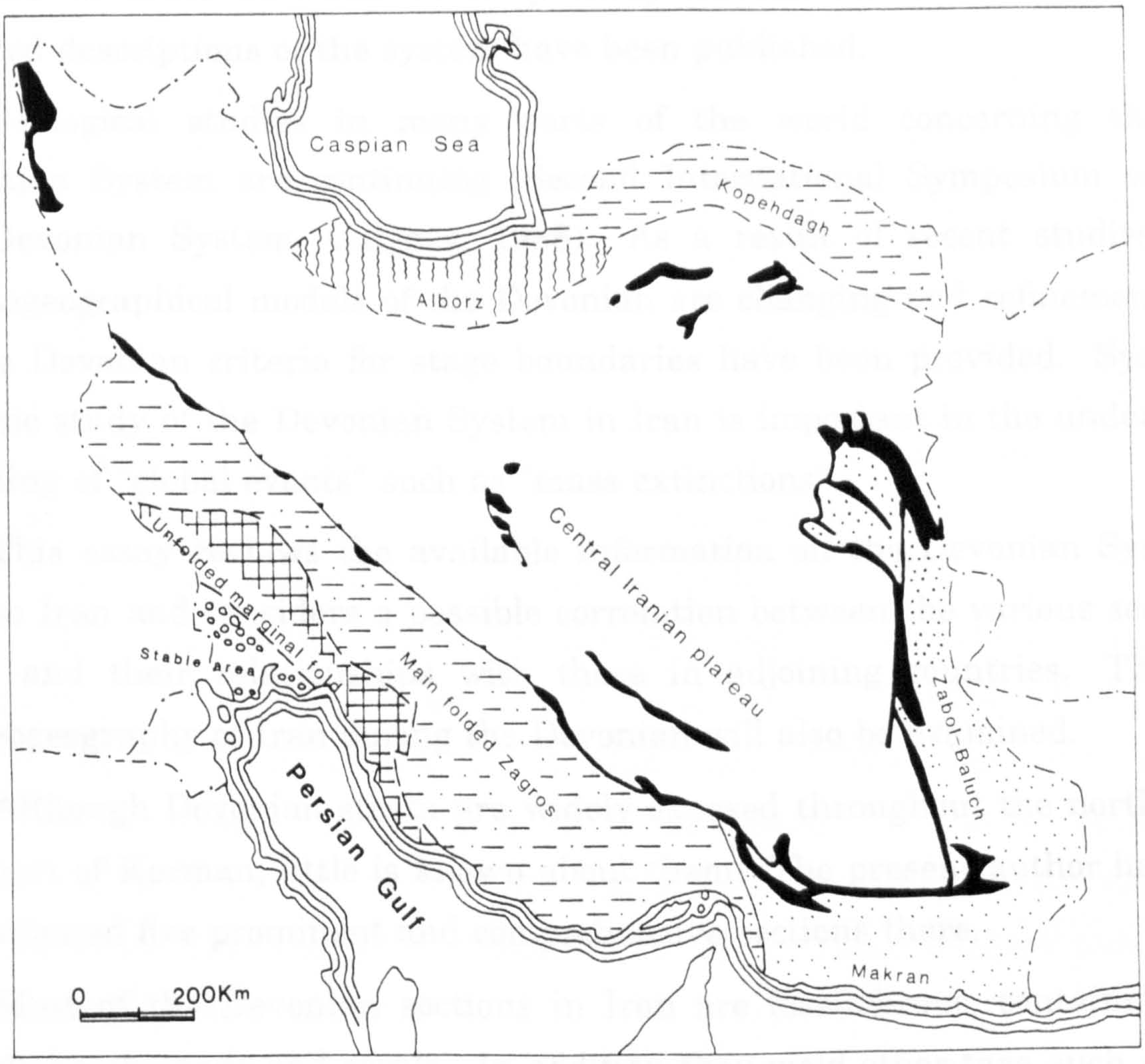


Figure 2.1- Iranian major tectonic - sedimentary units (after Berberian and King , 1984) .

Stable area

Unfolded and marginal fold zone

Main folded Zagros and Kopehdagh

Zabol-Baluch and Makran trough

Alborz Mountains

Central Iranian Plateau

Ophiolite zones

Between the end of the 19th century and the middle of the present century the Devonian System was sporadically examined. Durkoop et al. (1967) and Gaetani (1967) evaluated the available information on the Devonian rocks in Iran, Afghanistan and Pakistan. In regard to palaeontological and sedimentological similarities, they found the Devonian formations in these countries to be possibly correlative. Since then no detailed descriptions of the system have been published.

Geological studies in many parts of the world concerning the Devonian System are continuing (Second International Symposium on the Devonian System, Calgary, 1988). As a result of recent studies, palaeogeographical models of the Devonian are changing and refinement of the Devonian criteria for stage boundaries have been provided. Systematic study of the Devonian System in Iran is important in the understanding of "global events" such as "mass extinctions".

This essay reviews the available information on the Devonian System in Iran and considers a possible correlation between the various sections and their relationships with those in adjoining countries. The palaeogeography of Iran during the Devonian will also be examined.

Although Devonian strata are widely exposed throughout the northern part of Kerman, little is known about them. The present author has investigated five prominent and comprehensive sections there.

Most of the Devonian sections in Iran are fossiliferous, containing mainly brachiopods and corals. In addition they yield other taxa such as gastropods, crinoids, bryozoa and palynomorphs. Some fish fragments, trilobites and conodonts also have been reported in the Devonian rocks. The writer has focused his studies on brachiopods, corals and palynomorphs because they are the most abundant fossils in the Kerman region. They are also more reliable than other faunas of this region for biostratigraphic study. The brachiopod faunas belong to the Old World Realm of Boucot (1984).

The local sedimentary facies generally consist of clastics and marine carbonates with minor interbeds of shale and marl. The strata range variously in age from Lower to Upper Devonian.

2.2 PREVIOUS WORK

Devonian strata in Iran were first reported by DeVeneuil in the publication by Viquesnel (1850) from the Central Alborz Mountains about 100 km southwest of Gurgan (north Iran). Lotus (1855) gave the first comprehensive treatise on Iranian geology. His map extended from Lake Van in Turkey to southeast Shiraz and Esfahan to the Persian Gulf. Other pioneer stratigraphical work in Iran was carried out about the end of the last century and the beginning of the present. During the last thirty years systematic geological surveying has been done mainly by the Geological Survey of Iran and the Iranian Oil Company.

The first detailed geological map of Iran (scale 1:250,000) was produced by the Oil Company in 1959. Since then numerous publications have appeared on the geology of the Zagros Mountains and the Alborz Mountains. However, many areas such as the southeastern part of the country have been subjected to reconnaissance field work only. Durkoop et al. (1967) and Gaetani (1967) found similarities between the lithology and stratigraphy of Afghanistan, Iran and Pakistan. Allavi-Naini (1972), Aghanabati (1977), Bozorgnia (1973), Dimitrijevic (1973), Movahhed et al. (1968), Romanko (1984), Ruttner et al. (1968), Sharkovski et al. (1984), Stöcklin (1968, 1973, 1977) and Zahedi (1973, 1976) have recorded systematic geological exploration in Iran. These authors' publications contain basic information.

Devonian brachiopods from northern and northeastern Iran, studied by Brice et al. (1973), Gaetani (1965, 1967), Sartenaer (1966, 1968) and Sartenaer and Plodowski (1975), reveal identical taxa. Although there is some similarity within the brachiopod communities from the formations in the north and northeast, there are differences from the brachiopod communities in central Iran.

Systematic descriptions of corals from the Devonian rocks in the northeast and north Iran by Brice et al. (1973) and by Ghods (1982) include many taxa such as *Disphyllum caespitosum, Macgeea, Hexagonaria, Ceratophyllum dohmi, Heliophyllum halli, Thamnophyllum* *caespitosum* and *Tabulophyllum*. Most of these taxa have now also been found by the writer in the Kerman region.

Goniatites provide valuable data regarding stage boundaries in the Devonian System. In a pioneer study in the Tabas area (northeast Iran), Walliser (1966) identified the Upper Devonian genera *Manticoceras, Cheiloceras, Prolobites, Platyclymenia, Clymenia*, and *Wocklumeria*. He concluded that most of the Iranian forms are identical to those in Asia, Europe, Africa and North America.

Golshani and Janvier (1974), Janvier (1974), and Janvier et al. (1981) recorded Devonian dipnoans and elasmobranchs from the Upper Devonian in Kerman. These authors indicated that the tooth plates of *Rhinodipterus* sp. in Iran show marked differences from those of the genus in the Upper Devonian of Europe. On the other hand, their assigned age for the basal carbonate unit of the Hutk section is consistent with the age determination based on the brachiopods by the writer.

Palynological studies are becoming increasingly important for Devonian correlation, especially where the sequences contain no other index fossils. Devonian spores and acritarchs were reported by Kimyai (1979) from formations in Hasanakdar, north Iran, and by Ghavidel-Syooki (1989) in the Faraghan Mountains, south Iran. The Faraghan Formation was previously thought to be of the Carboniferous in age; Ghavidel-Syooki (1989) determined a Middle to Upper Devonian age for the formation. On finding Gondwana spores, e.g. *Deltotosoma intosum* and *Papalongabata annulata* there, he concluded that Iran was part of Gondwana in Devonian time.

2.3 REGIONAL STRUCTURAL SETTING

The Lower Palaeozoic strata beneath the Devonian rocks throughout Iran, Arabia, parts of Pakistan, Afghanistan, Turkey and Jordan have a similar stratigraphy. Precambrian rocks consist mainly of rhyolite, basalt and evaporite deposits. The sequences of Upper Precambrian were followed by detrital sediments, red arkosic sandstones and shales of Cambrian to Silurian age.

Stratigraphic evidence together with palaeomagnetic data indicate that in this period of time, Iran was part of northern Gondwana (Berberian and King, 1981). Similarity of stratigraphic sequences shows a widespread stable continental margin of Gondwana during Palaeozoic time (Cherven, 1986).

The consolidation of the Precambrian basement of Iran was followed by discontinuous sedimentary deposition (Fig. 2.2). Stöcklin (1968) suggested, that although sedimentary facies and thickness of individual formations may change within certain limits, in general the total thickness of the Palaeozoic sequences is constant, i.e. between 3 to 4 km in most sections except in Tabas. Ruttner et al. (1968) discovered that the Palaeozoic strata in the mountains of Shirgesht-Ozbak-Kuh (northeast-central Iran), in the Tabas region, are probably the thickest and most complete Infracambrian to Devonian (about 7 km) in the Middle East. In a short distance (about 50 km) to the southwest of that section, the thickness drops to zero. This variation suggests the existence of a graben-like feature in Tabas in Early Palaeozoic time.

The Palaeozoic succession, for the most part without volcanic activity, granite intrusion and regional metamorphism, indicates the persistence of a vast tectonically stable platform during this period of time (Stöcklin, 1973). Only in two localities have volcanic rocks been found, from the Lower and Upper Devonian formations in central and eastern Alborz and in the Lower Devonian of the Anarak area, central Iran. The cause of these volcanic events in respect to tectonic movements has not yet been considered. However, Brookfield and Gupta (1988) believe that the Lower Devonian basalt of northern Iran marks the initial break-up of northern Gondwana.

The presence of continental deposits of Upper Silurian age and the lack of Lower Devonian rocks, together with the thickness and facies changes in the western and central Alborz, reveal a local uplift in post-Silurian time.

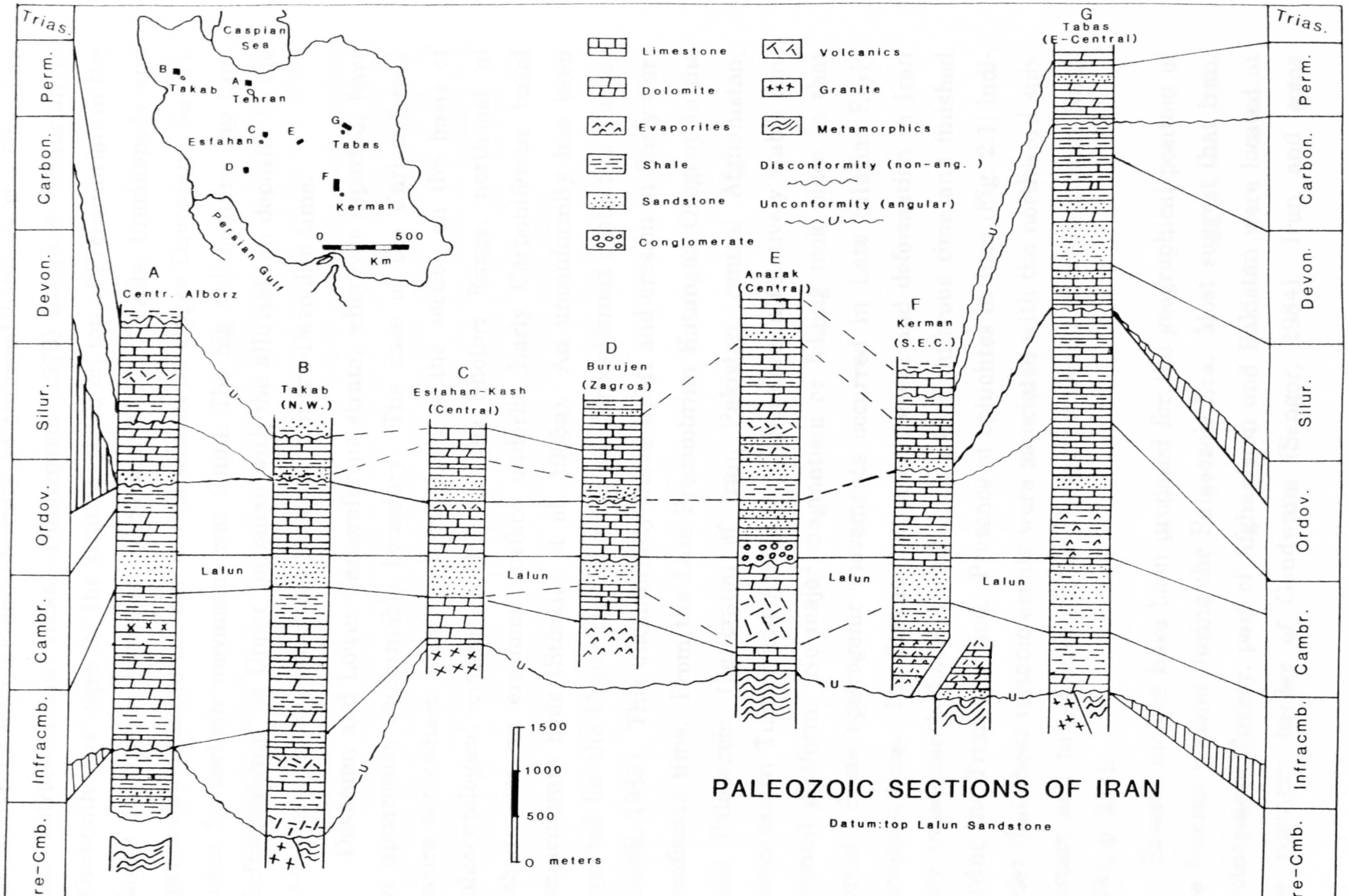


Figure 2.2 – Correlation of stratigraphic sections of the Palaeozoic rocks in Iran.

The Lower Devonian contact with older Palaeozoic formations is everywhere a disconformity. Only in Shams Abad northwest of Kerman can a distinct angular unconformity be observed between the Devonian and "Infracambrian" rocks. Dimitrijevic (1973) assigned "?Silurian to ?Carboniferous" ages for the strata exposed on top of Precambrian in the Zangu Mountains northeast of Shams Abad. Corals, brachiopods and spores now indicate the age of this section as Upper Devonian. No evidence for tectonic movement was found. The big sedimentary gap from "Infracambrian" to Upper Devonian with the alluvial fan deposits at the base of the section indicate a local uplift in pre-Devonian time.

Devonian and Lower Carboniferous strata, wherever reported, have an apparently conformable boundary. The base of the Carboniferous occurs somewhere within a broad span of the section on the basis of palaeontological evidence. Only at the Shotori Range, northeast of Tabas, does an erosional surface underlie Early Carboniferous basal conglomerate beds (Stöcklin et al. 1965a). An unconformity has been reported for the Upper Devonian-Lower Carboniferous contact in Turkey (Gedik, 1988). This unconformity shows uplift and erosion in Early Carboniferous time. From the Late Precambrian Katangan Orogeny to the Late Palaeozoic, the craton of Iran, Pakistan, central Afghanistan, southeastern Turkey and Arabia was, therefore, a relatively stable continental platform. No major magmatism or folding took place in that period. Some epeirogenic movements occurred in Late Silurian-Early Devonian time. The first major tectonic event and deformation in Iran may subsequently have started during Carboniferous time and finished during the Triassic period. Presence of ophiolites in Iran (Fig. 2.1) indicates that these tectonic events were associated with the northward subduction and the closure of the Hercynian Ocean (Berberian and King, 1981, p. 213).

Several models have been proposed for the geographical position of the Iranian plateau during the Palaeozoic Era. Most suggest that Iran, southeastern Turkey, part of Afghanistan and Pakistan were located at the northern border of Gondwana (Sengor, 1984). Iran and some surrounding countries were becoming detached from Arabia and collided with Asia in Late Palaeozoic time. Iran moved as one or as several continental fragments across the Tethys Sea, toward the end of the Late Triassic period, and a new ocean crust was produced to form the "High-Zagros Alpine Ocean".

2.4 STRATIGRAPHY

Exact boundaries between the Devonian Series in Iran have not yet been established. This is essentially because of the lack of reliable data. Correlation between the sections is mainly based on brachiopods and/or corals. However, some exposures were also correlated with regard to their facies similarity and/or their stratigraphical positions (Fig. 2.3). A quantitative analysis of the brachiopod distributions, such as presented by Boucot et al. (1969), is required for establishing a more convincing correlation between the Devonian sequences throughout Iran.

For convenience the Devonian outcrops can be divided into four parts and are described separately.

1. The Alborz Ranges in the north
2. The Kopehdagh in the northeast
3. The central part
4. The Faraghan Mountains in the south.

They represent the different parts of a single sedimentary basin (Fig. 2.4).

2.4.1 The Alborz Ranges

Lower Devonian: Lower and Middle Devonian fossils have not been identified with certainty from the western and central part of the Alborz Mountains. However, an extensive section of the Devonian rocks has been reported at Khoshyielagh in the eastern Alborz (Bozorgnia, 1973; Hamdi and Janvier, 1981). The basal formation of the Khoshyielagh outcrop is composed of approximately 300 m of conglomerate, diabase, white and reddish sandstone, shale and limestone.

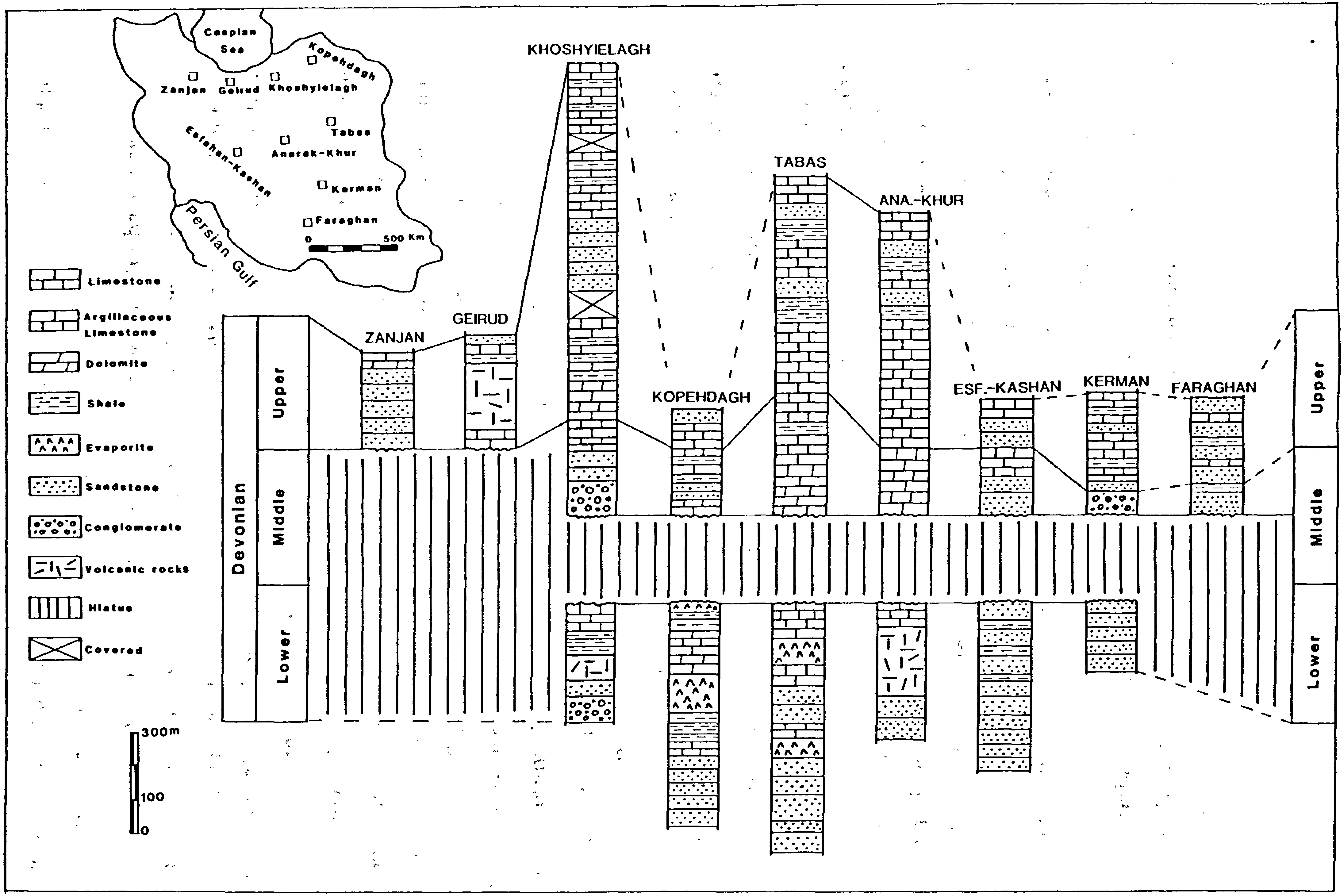


Figure 2.3-Correlated stratigraphic sections of the Devonian in Iran.

Middle Devonian: Middle Devonian rocks in the central and eastern Alborz have been attested by foraminifera, algae and brachiopods. The Khoshyielagh section, 15 km west of Khoshyielagh village contains about 260 m of Middle Devonian conglomerate and siltstone with interbedded grey argillaceous to silty limestone beds.

No angular unconformity has been reported for the base nor at the top of the Middle Devonian strata in the Alborz Mountains. Brachiopods, e.g. *Spinatrypa* sp., *Spinocyrtia* sp., *Athyris* sp. and *Chonetes* sp. dominate the local faunas; tentaculites and trilobites have also been reported from the Khoshyielagh section.

Upper Devonian: More reliable data are available for the Upper Devonian of northern Iran which has a wide distribution, extending from Azarbaiejan northwest through the central part to the eastern Alborz (see Fig. 2.3). In general, Upper Devonian formations in the Alborz Mountains are comparable to those of northern Afghanistan and Pakistan (Gaetani, 1967). Upper Devonian sections are described below.

A. Zanjan (northwest). Lower and Middle Devonian rocks are missing in the Palaeozoic section of Zanjan. A marine Upper Devonian succession, exceeding several hundred meters in thickness, is of gray limestone with Frasnian *Rhipidiorhynchus*, followed by sandstone and well stratified limestone beds with Famennian brachiopods.

B. The Geirud Formation (Assereto, 1963) in the Geirud Valley, north-central Alborz, about 35 km north of Tehran, rests unconformably upon the Cambrian Mila Formation. Its lower limit has been dated as Upper Frasnian by the presence of *Cyrtospirifer verneuili*, *Camarotoechia* and other brachiopods (table 2.1). The sequence continues upward with beds of Famennian and Lower Carboniferous age, but the upper limit of the formation is of uncertain age. Assereto and Gaetani (1964) subdivided the formation into four members (a, b, c and d). Member (a) (lowest) has been referred to as Late Devonian and the other three members are Carboniferous in age.

Table 2.1 – Some of the Devonian brachiopods reported in Iran and Afghanistan

Order	Taxa	Location[1]					
		Alb	Esf-Kas	Ana-Khur	Tab	Ker	Afg
Orthida	*Rhipidomella sp.*					x	
	Schizophoria striatula				x		
Rhynchonellida	*Camarotoechia nalivkini*	x					x
	Camarotoechia sp.			x	x		
	Centrorhynchus charakensis		x				
	Ce. turannica	x					
	Coeloterorhynchus tabashensis				x		
	Cyphoterorhynchus arpaensis		x		x	x	x
	Cy. bisinus		x				
	Cy. koraghensis		x			x	
	Eoparophorhynchus maclareni	x					
	Hypothyridina cuboides				x		
	Paurorhyncha biknensis	x				x	
	Ptychomaletoechia deltidialis	x	x				
	Pt. elburzensis	x				x	
	Rhipidiorhynchus elburzensis	x	x				x
	Rh. kotalensis	x	x			x	x
	Rossirhynchus adamantinus	x					
Spiriferida	*Anathyris sp.*					x	
	Anatrypa sp.					x	
	Atrypa altryola			x			
	At. grossheimi			x			
	At. reticularis				x		
	Athyris chitralensis	x				x	
	Ath. communis				x		
	Cleiothyridina coloradensis		x	x		x	x
	Cl. kasbassica	x					
	Cl. reticulata	x		x	x	x	x
	Composita sp.	x	x			x	x
	Cyrtospirifer asiaticus					x	x
	Cy. bisinus		x				x
	Cy. chantaginicus	x					
	Cy. disjunctus			x	x		
	Cy. koraghensis				x		
	Cy. schelonicus	x				x	x
	Cy. supradisjuctus					x	
	Cy. syringothyriformis	x				x	x
	Cy. verneuili	x	x	x	x	x	x
	Cy. wangi		x				

[1]Alb = Alborz, Esf-Kas = Esfahan-Kashan, Ana-Khur = Anarak-Khur, Tab = Tabas, Ker = Kerman, Afg = Afghanistan

Table 2.1 – (Continued)

Order	Taxa	Location[1]					
		Alb	Esf-Kas	Ana-Khur	Tab	Ker	Afg
Speriferida	*Dichospirifer piriformis*	x					
	Di. thylakistoides					x	
	Dmitra sp.	x		x	x	x	x
	Eobrachytris proovalis		x				x
	Eo. struniatus			x		x	x
	Eleutherokoma robatense						x
	Punctospirifer sp.	x					
	Reticulariopsis lemaitreae					x	
	Sphenospira sp.					x	
	Spinatrypina sp.	x		x	x		
	Sp. chitralensis					x	x
	Sp. robusta				x		
	Sp. tubaecostata				x		
	Syringothyris sp.				x		
	Torynifer sp.					x	x
	Tylothyris mesacostalis				x		
	Ty. subvaricosa					x	
	Uchtospirifer multiplicatus	x				x	x
	Uchtospirifer sp.		x				
Strophomenida	*Buxtonia scabriala*	x					x
	Leptaena sp.					x	
	Praewaagenoconcha sp.					x	
	Productella sp.	x	x	x	x		x
	Pr. hirsutiformis				x		
	Retichonetes sp.		x			x	
	Schellwienella sp.		x				
	Sc. percha					x	
	Strophonella productoides				x		
	Whidbornella productoides					x	
Terebratulida	*Cryptonella tripliata*					x	

[1]Alb = Alborz, Esf-Kas = Esfahan-Kashan, Ana-Khur = Anarak-Khur, Tab = Tabas, Ker = Kerman, Afg = Afghanistan

Member (a) consists of about 335 m of sandstone and fossiliferous limestone with several phosphatic layers (Movahhed et al., 1968). It is followed by plagioclase basalt, conglomerate, sandstone and fossiliferous limestone. It is attributed to the Upper Frasnian and Famennian.

The following brachiopods are common in member (a) and have been reported in many Upper Devonian sections in Iran (table 2.2): *Productella* sp., *Ptychomaletoechia elburzensis, Camarotoechia nalivkin, Paurothyncha bikniensis, Eoparorhynchus muclareni, Gastrodetoechia iranca, Cyrtospirifer verneuili, Cy. Changangincus, Cy. syringothyriformia, Athyris chitralensis, Composita,* (Gaetani, 1965)

C. Djam Section. Devonian rocks are also exposed in the Djam area, 250 km east of Tehran. The Lower Devonian there accounts to 413 m of sandstone, shale, gypsum and dolomite. The upper part of the Djam section is formed of 200 m of limestone containing brachiopods, tentaculites and trilobites which indicate Middle to Upper Devonian age (Allavi-Naini, 1972). Carboniferous beds are missing in the Djam section and the Devonian strata are overlain by Permian rocks.

D. Khoshyielagh Section. eastern part of the Alborz Mountains (approximately 350 km northeast of Tehran), were studied by Bozorgnia (1973). The section contains Lower to Upper Devonian strata. The upper part of the unit consists of about 1070 m argillaceous limestone, fossiliferous and bioclastic limestone, quartz sandstone and dolomite. Brachiopods are common in this section, e.g. *Cyrtospirifer schelonicus, Dichospirifer piriformis* and *Spinatrypa sp.* (see also table 2.1).

Most of the brachiopod taxa from the northern part of Iran have also been reported from the Devonian formations in Afghanistan.

2.4.2 Kopehdagh

The Lower Devonian is well known in Kopehdagh, approximately 280 km northeast of the Khoshyielagh section, and has the following members: a) basal member, 210 m, red to brown siltstone; b) lower evaporite member, 290 m, gypsum, red brown and green shale with dark thin bedded dolomite; c) carbonate member, 80 m, dolomite and limestone having brachiopods and corals; d) upper evaporite member, 75 m, gypsum and shale (Khosrow-Tehrani, 1985, p. 476).

Middle-Upper Devonian rocks in this area are 290 m of limestone, dolomite, shale and siltstone containing brachiopods, corals, gastropods and trilobites. The faunas confirm the Middle to Late Devonian age.

2.4.3 Central Iran

Here there is an almost complete succession within the Devonian System exposed locally in the following regions: a) Tabas, b) Esfahan and Kashan, c) Anarak and Khur, d) Kerman. The succession is subdivided into formations comparable to those with Devonian sections in other areas of Iran (Fig. 2.3).

a) Tabas region. The best known Devonian outcrops are found here in northeast central Iran. The Devonian sections are exposed in the Gushkamar and Ozbak-Kuh areas north of Tabas. The Devonian is about 1500 m thick and distributed between four units: Padeha Formation, Sibzar Dolomite Formation, Bahram Limestone Formation and Shishtu Formation. Their stratigraphy is summarized in table 2.2. No fossils have been reported so far from the Padeha Formation. Because it is resting directly on the Upper Silurian strata (Niur Formation), it has been referred to the Early Devonian in age.

Weddige (1984) found that conodont faunas from the Devonian formations in central Iran compare closely to those of other basins, e.g. Germany, and pointed out that an Eifelian and probably also Upper Emsian hiatus is evident between the Padeha and Sibzar Formations.

Table 2.2 – Stratigraphic sequences exposed in the north Tabas area. (after Ruttner, Nabavi and Hajian, 1968)

Group	Formation	Thickness (m)	Subdivision	Lithology	Age
Ozback-kuh Group	Sardar Formation	600-900	Sardar 2	shale, sandy marl, limestone and conglomerate	Early Permian to Late Carboniferous
			Sadar 1	shale, marl, limestone and sandstone	Late-Early Carboniferous
	Shishtu Formation	300-400	Shishtu 2	limestone and marl, partly nodular	Early Carboniferous (Tournaisian-Visean)
			Shishtu 1	shale, limestone and sandstone	Early Tournaisian Late Devonian (Frasnian-Famennian)
	Bahram Limestone Formation	300-500	Bahram 2	limestone, dolomite and shale	Late Devonian (Frasnian)
			Bahram 1	limestone	Middle Devonian (Givetian)
	Sibzar Dolomite Formation	100		Dolomite	Early Middle Devonian
	/ /	/ /	/ /	/ /	Eifelian
Gushkamar Group	Padeha Formation	700		sandstone, dolomite and marl	Late-Early Devonian
	Niur Formation	600		limestone, sandstone and marl	Silurian

Furthermore, he suggested that the "Eifelian hiatus' exists throughout central and northern Iran.

Undetermined corals and brachiopods are the only taxa found from the Sibzar Dolomite Formation. An early Middle Devonian age was assigned to the formation from its stratigraphic position (Stöcklin, 1977, p. 228).

Bahram Limestone contains several brachiopods, such as *Cyphoterorhynchus arpaensis, Cyrtospirifer verneuili,* and *Productella hirsutiformis* (see Stöcklin, 1977, p. 47 for details). Conodonts were also determined from this formation, including *Spathognathodus bipernnatus, Icriodus nodosus* and *I. alternatus.* In addition, corals, e.g. *Heliolites* sp. and *Alveolites* with *Tentaculites* sp. and trilobite fragments are also reported from the Bahram Limestone. Thus a Givetian-Frasnian age is claimed for the formation.

The Shishtu Formation has been subdivided here into members Shishtu 1 and Shishtu 2. The boundary between the two is marked by a black shale unit which was taken as the top of Shishtu 1. Shishtu 1 has been referred to as Frasnian-Famennian and probably including Early Tournaisian (Stöcklin, 1977, p. 225). It contains brachiopods, e.g. *Dmitria* sp., *Cyrtospirifer pamiricus* and *Athyris communis.*

Goniatites reported from the upper part of Shishtu 1 are *Manticoceras, Platyclymenia (Pl.) quenstedti, Pl. (Pl.) biferum* and *Sporadoceras.* In addition, corals, crinoids, bryozoans and trilobites are also found in Shishtu 1.

Most of the faunas from the Tabas area have also been reported from the Devonian formations in central and northern Iran.

b) Esfahan and Kashan (west central Iran). Here Lower Devonian rocks consist of about 500 m red sandstone, dolomitic sandstone and sandstone interbedded with reddish shale (Fig. 2.3).

Middle and Upper Devonian strata are exposed to the south of Kashan and in northeast Esfahan but the local boundary between the Middle and Upper Devonian is not well defined. The Middle Devonian is composed of 140-400 m sandstone, dolomite and limestone. The strata contain many brachiopods, which include *Chamarotoechia* sp., *Cyphoterorhynchus arpaensis, Cy. kotaghensis, Ptychomaletoechia deltidialis, Cyrtospirifer bisinus, Rechonetes* sp., *Schellwienella* sp. and *Productella* sp. These brachiopods are common in central Iran.

The Upper Devonian sequences are composed of approximately 200 m of limestone, sandstone and dolomitic limestone, rich in fossils. The latter are mainly brachiopods, e.g. *Cleiothyridina coloradensis* and *Uchtospirifer* sp. (see also table 2.1).

c) Anarak and Khur (central Iran). The Lower Devonian is formed of about 300 m red and white quartz sandstone and diabase with a few intercalations of dolomitic limestone in the Anarak area approximately 220 km northeast of Esfahan. No fossils have been reported from these rocks. The ?Lower Devonian age is based on the stratigraphic position between the underlying Silurian Niur Formation and overlying Middle Devonian Sibzar Dolomite (Romanko, 1984).

In the Khur area about 120 km northeast of Anarak, Lower Devonian formations increase in thickness towards the east where they are 350-500 m of dolomitized limestone, quartzite and sandy dolomite. Several representative dolomite and dolomitized limestone exposures of the Sibzar Dolomite Formation (Early Middle Devonian) were reported in the southeast of Anarak and Khur areas. The total thickness of these rocks is 80 m in Anarak and as much as 145-270 m in the Khur area. Certain species of corals within the sequence and stratigraphic relationships together indicate the Middle Devonian age for the sections (Romanko, 1984).

The Bahram Limestone Formation in the southeast Anarak and south Khur areas consists of 350-570 m of predominantly dark gray limestone. The formation contains many brachiopods and corals of Middle to Upper Devonian age, the most common being *Camarotoechia* sp., *Atrypa grossheimi, Cyrtospirifer verneuili, Spinatrypa* sp. and *Productella* sp. (see table 2.1).

Corals are *Heliophyllum* sp., *Hexagonaria* sp., *Neostringophyllum* sp., *Phillipsastraea* sp., *Scoliopora* sp., *Thamnopora reticulata* and *Tryplasma* sp. Many of these have been found elsewhere in Iran and Afghanistan.

The Shishtu Formation in the Anarak and Khur areas amounts to about 264-400 m of mudstone, shale, sandstone and limestone containing brachiopods and corals. The faunas, e.g. those containing *Cleiothyridina coloradensis* and *Cyrtospirifer disjunctus* confirm an Upper Devonian to Lower Carboniferous age.

d) Kerman (southeast central Iran). Devonian rocks are widely exposed in the northern part of Kerman. The present author studied five Devonian sections in this area (see details below). Unfossiliferous red sandstone beds exposed at the base of the Hutk section, northeast Kerman, have been referred to as Old Red Sandstone facies (Clapp, 1940; Stöcklin and Setudehnia, 1977). The lower limit of the red beds does not crop out but the exposed thickness is about 110 m.

The dominant lithology is a medium to thick bedded arenite with medium to fine grained sand and calcite-dolomite cement containing a large quantity of iron oxide. The age given is solely based upon the superposition of Upper Devonian beds. However, an erosional surface with a 2 m thick microconglomerate bed is present on top of red sandstone. The sequence is extended for about 3-4 km in this section but it has not been seen elsewhere in Kerman.

Middle Devonian strata have been reported at several places north and northeast of Kerman (Hückreide et al., 1962). Nevertheless, the present writer has not found fossils of this age within the study area. A conglomerate unit up to 56 m thick was discovered beneath Upper Devonian strata in the Shams Abad section, northwest Kerman. The conglomerate is overlain by sandstone which grades to sandy limestone and limestone beds. No erosional surfaces were found in this section. The age of the conglomerate is possibly Middle Devonian.

Upper Devonian strata consist of about 200-380 m limestone, sandy limestone, argillaceous limestone, dolomite, sandstone and shale. They are highly fossiliferous. Thirty-one brachiopod taxa, e.g. *Cyphoterorhynchus arpaensis* and *Dichospirifer thylakistoides* with eight taxa of Rugosa and Tabulata corals, e.g. *Disphyllum caespitosum* and *Alveolites* sp. were determined in this area. In addition, twenty-nine spore and acritarch taxa such as *Acinosporites acanthomammillatus* and *Chomotriletes vedugensis* were also found in Kerman. The fossils indicate Frasnian-Famennian ages for the section here.

Table 2.1 shows that most of the brachiopods in Iran were also found in Afghanistan. About 60% of the brachiopod taxa in the Kerman area and Afghanistan are the same. This similarity may indicate that a single and/or similar depositional environment existed in these two regions.

2.4.4 Faraghan Mountains

Rocks of Devonian age have not been reported from the southern part of the Zagros Mountains. However, the presence of the Devonian has been suggested from the recent investigation of palynomorphs in the Faraghan Mountains (Ghavidel-Syooki, 1989). The Faraghan Formation there, approximately 80 km north of Bandar Abbas (Fig. 2.3) is composed of about 310 m of sandstone interbedded with shale and limestone. Middle Devonian rocks lie disconformably upon the Silurian.

Because of the lack of marine invertebrate fossils, a Permo-Carboniferous age was previously assigned to the Faraghan Formation. However, certain spores and acritarchs, e.g. *Retusotriletes distonensis, Densosporites devonicus, Geminospora puntata* and *Ancyropora ancyrea*, proved the presence of Middle and Upper Devonian there, but Famennian fossils have not been found at this section (Ghavidel-Syooki, 1989).

2.5 PALAEOGEOGRAPHY

Data on the Devonian stratigraphy of Iran, in contrast to many other areas of the world (e.g. Second International Symposium on the Devonian System, 1988), are still relatively few in recent publications. Thus a tentative palaeogeographic reconstruction for the Late Devonian (Fig. 2.4) shows no more than a general pattern of the sedimentary facies at that time. The present writer has studied the known literature on the sedimentology and palaeontology of the Devonian rocks in Iran. Although knowledge of local Iranian Devonian palaeogeography improves, it is still rudimentary. One of the main problems concerns the lack of fossils from the Early Devonian.

No Devonian marine fossils have been found within the southern and southwestern parts of Iran. Only in the Faraghan Mountains, 80 km north of Bandar Abbas, do arenaceous deposits contain Devonian spores and acritarchs (Ghavidel-Syooki, 1989). No Devonian rocks have been reported from the entire eastern part of Iran (Stöcklin, 1972).

Southwest and east Iran were uplifted by Caledonian epeirogenic movements (Davoudzadeh et al., 1986). Marine sediments were deposited over the central and northeast in Silurian-Devonian time. This sedimentary cycle was terminated by the "Eifelian hiatus".

As shown in the reconstructed palaeogeography map (Fig. 2.4), sandstones are mainly restricted to the west, northeast and southern parts of the area. Carbonate sediments interbedded with sandstone and shale beds, containing marine invertebrate fossils, occur over the rest of the region. Sedimentary sequences of sandy limestone, shale and sandstone with corals and brachiopods indicate that predominantly a shallow water platform developed from the northeast Alborz to the Kopehdagh and extended southward to the Faraghan Mountains in the south. A study of Devonian formations in Saudi Arabia by Boucot et al. (1988) indicates a similar sedimentary environment for that area.

In the northern Iran and Kopehdagh areas Devonian sediments were supplied from sources in the northwest and the northeast, respectively. In the Kerman and Faraghan areas the sediments were supplied from the eastern land mass (Lut block). In the Esfahan area the exposed Old Red-type sandstone, a thickness of about 500 m, was supplied from the western part of Iran. Lithofacies and the isopach map of the Silurian-Lower Devonian of Iran by Davoudzadeh et al. (1986) shows a similar pattern to the palaeogeography map of the Devonian (Fig. 2.4) The only difference is that the Silurian upland areas west of Alborz and northwest of Tabas became shallow marine environments in Late Devonian time.

The thickest succession of Devonian rocks is found in the Tabas region, northeast Iran. It is possibly due as much to an uprising of the source area (Lut block) east of Tabas (Stöcklin, 1966) as to local subsidence. A second landmass (Tabas block) also existed to the western side of the area. A narrow basin striking northwest-southeast thus subsided between the two blocks.

As shown in the reconstructed palaeogeography map (Fig. 2.4), the exact boundary between the land and marine environment is uncertain due to the lack of data. It is possible that clastic sediments were deposited throughout the southwestern part of the basin from Zanjan to Esfahan and Faraghan, but there are no reliable data to prove that.

Evaporites (gypsum) are deposited in the Lower Devonian formations in Khoshyielagh (north Iran), Tabas (northeast Iran) and in the Djam area, 250 km east of Tehran. They indicate a dry warm climate for that period of time in northern Iran. This is also confirmed by the palaeogeography map of the Devonian by Liao and Ruan (1988), which shows that Iran was located in the subtropical region (15° to 30° south of the equator). The above mentioned evaporites are not shown in Zharkov's (1988) map of the Devonian evaporite basins of the world. This may be due to lack of data or because of their local nature.

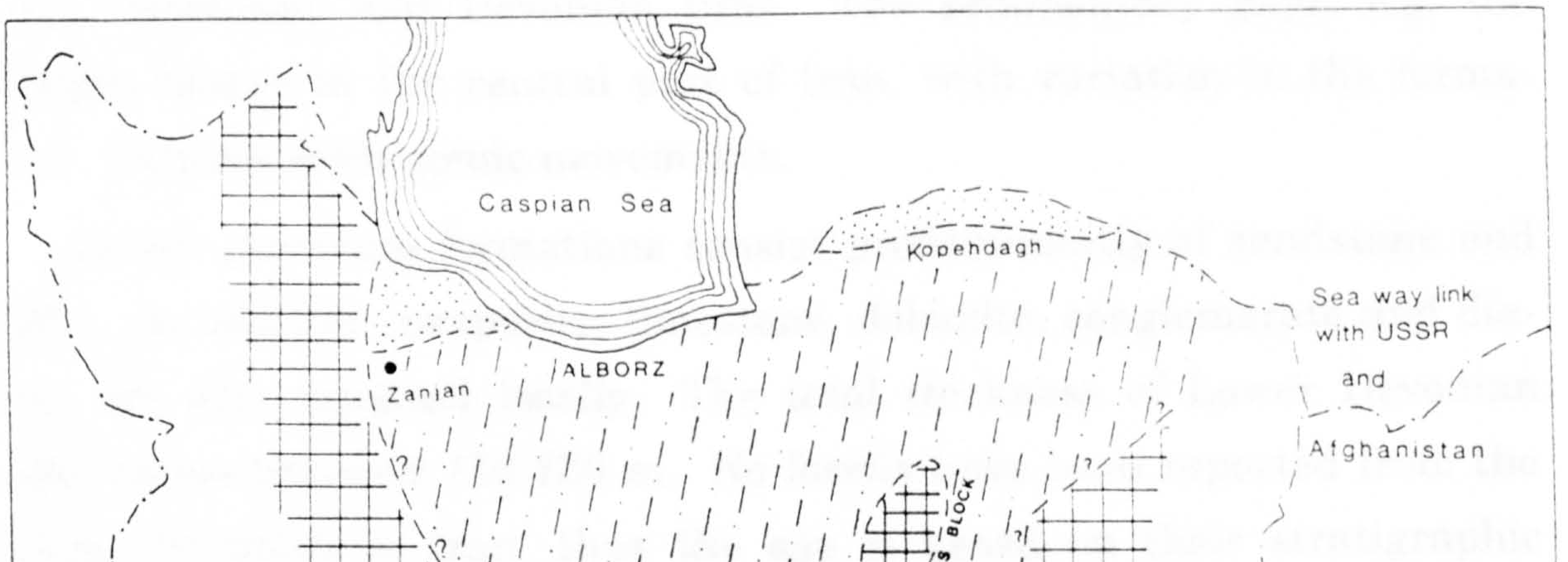


Fig. 2.4 -Palaeogeography map of the Late Devonian in Iran.

Marine off-shore environments
(predominantly carbonate)

Near shore environments (sandy)

Land

2.6 SUMMARY AND CONCLUSIONS

Lower Palaeozoic strata throughout Iran have similar stratigraphical characteristics. In general, the sedimentary pattern of the Devonian rocks (Fig. 2.3) is very similar to the rest of the Palaeozoic succession (Fig. 2.2). The thickest sequences of both Early Palaeozoic and Devonian occur in the Tabas area and northeastern Alborz. This similarity possibly suggests a relatively uniform depositional environment throughout early Palaeozoic and Devonian time. The sedimentary gaps, e.g. the Eifelian hiatus in the central part of Iran, with variation in the formations, indicate epeirogenic movements.

Lower Devonian formations consist predominantly of sandstone and shale. In addition, evaporite, limestone, dolomite, conglomerate and diabase are also reported locally. The total thickness of Lower Devonian rocks varies between 110-730 m. No fossils have been reported from the Lower Devonian in Iran, thus the age is based on their stratigraphic position.

Middle Devonian formations (100-320 m) are mainly of dolomite and sandstone containing brachiopods, corals, conodonts and spores in north, central and southeast Iran.

Upper Devonian marine sediments are widespread, extending from northwest through the Alborz to northeast central Iran, Tabas, Kerman and as far south as north of Bandar Abbas. Dark limestones with brachiopods and corals predominate, but shaly and sandy facies are also reported; in addition gastropods, trilobites, crinoids, spores, acritarchs and fish fragments of Frasnian and Famennian age have been found.

The total thickness of the rocks attributed to the Devonian System in Iran ranges from a few hundred meters in the northwest to a maximum of 1870 m in the northern Tabas area (Fig. 2.3). The Devonian-Carboniferous boundary is within a transitional succession and the location is uncertain. A minor intraformational unconformity with a few thin conglomerate beds within the Lower Carboniferous occurs in the Shotori Range east of Tabas (Stöcklin, 1966). It may represent a marine transgression after a brief hiatus.

A gentle movement resulted in an uplifting of east and southwest Iran. Shallow marine Devonian sediments were deposited over a wide area from the northern part through central and southeastern Iran.

The formation of evaporites within the Devonian succession in northern Iran indicates a dry warm climate for that period of time.

CHAPTER 3

DEVONIAN STRATIGRAPHY OF KERMAN

3.1 INTRODUCTION

The Kerman province is located in southeastern central Iran. It lies between 53° and 59°E longitude and 25° and 33°N latitude, with an area of nearly 200,000 km^2. Most of the Kerman region has mountainous topography with several NW-SE trending ranges, separated by broad depressions. The climate is continental and arid with hot summers (up to 40°C) and very cold winters (about -14°C), especially in the mountains.

Sedimentary formations in Kerman range from Precambrian to Recent. The northern part of the region is covered mainly by sedimentary rocks, with little metamorphism and few igneous outcrops. However, the southern part of the area is covered by igneous, metamorphic and sedimentary rocks, with volcanic rocks predominating. The area was folded and faulted as the result of Late Hercynian and Alpine orogenic events.

The Precambrian successions in Kerman consist of about 500 m of marine clastic sediments containing radiolarite (Morad Series). The sequence is followed by a thick (600 m) succession of dolomites, sandstones and volcanic rocks (Rizu Series). The series passes into gypsum and dolomite interbedded with volcanic rocks, reaching a thickness of about 200 m (Desu Series).

The Precambrian formations are overlain by 400 m of sandstones (Dahu Formation) which are succeeded by limestones containing Middle and Upper Cambrian trilobites.

The successions from the Ordovician to Lower Devonian are relatively thin and consist of sandstones and dolomites with occasional interbedded limestones (Hückreide et al., 1962).

Devonian strata crop out in many places throughout the northern part of the Kerman region (Fig. 3.1). They overlie unconformably "Infracambrian" rocks in the Zangu Mountain, northwest Kerman. No other unconformity has been reported at the base of the Devonian outcrops. However, in most sections the lower contact of the Devonian is not exposed. According to Hückreide et al. (1962), the Upper Devonian and Carboniferous in most parts of the area are monotonous dolomites. The boundary between the two systems cannot be established due to the lack of fossils, and the presence of the Lower Carboniferous strata in the area of study is not established. A late Early-Late Carboniferous hiatus in the Kerman area has been reported by Weddige (1984).

In the present research the Devonian formations in the Kerman region were considered in order to provide data for the interpretation of the palaeoenvironments as well as correlation of the sections in this part of Iran. It is also hoped to establish the Frasnian/Famennian boundary in the Kerman area.

Five prominent outcrops were studied in detail. They are well exposed at the surface and not obscured by detritus or vegetation. The sections are easily accessible and include much of the Devonian succession in the region. The following localities were sampled and are described briefly:

1. Gerik Section, 75 km north of Kerman Town
2. Hutk Section, 30 km north-northwest of Kerman Town
3. Nedenu Section, 60 km north-northwest of Kerman Town
4. Shams Abad Section, 26 km north-northwest of Kerman Town
5. Tizi Section, 22 km north-northeast of Kerman Town

See Fig. 3.1 for the location of the sections.

3.2 STRATIGRAPHY

The outcrops in the study area were previously regarded as "Upper Cambrian-Devonian and locally Carboniferous" (Hückreide et al., 1962).

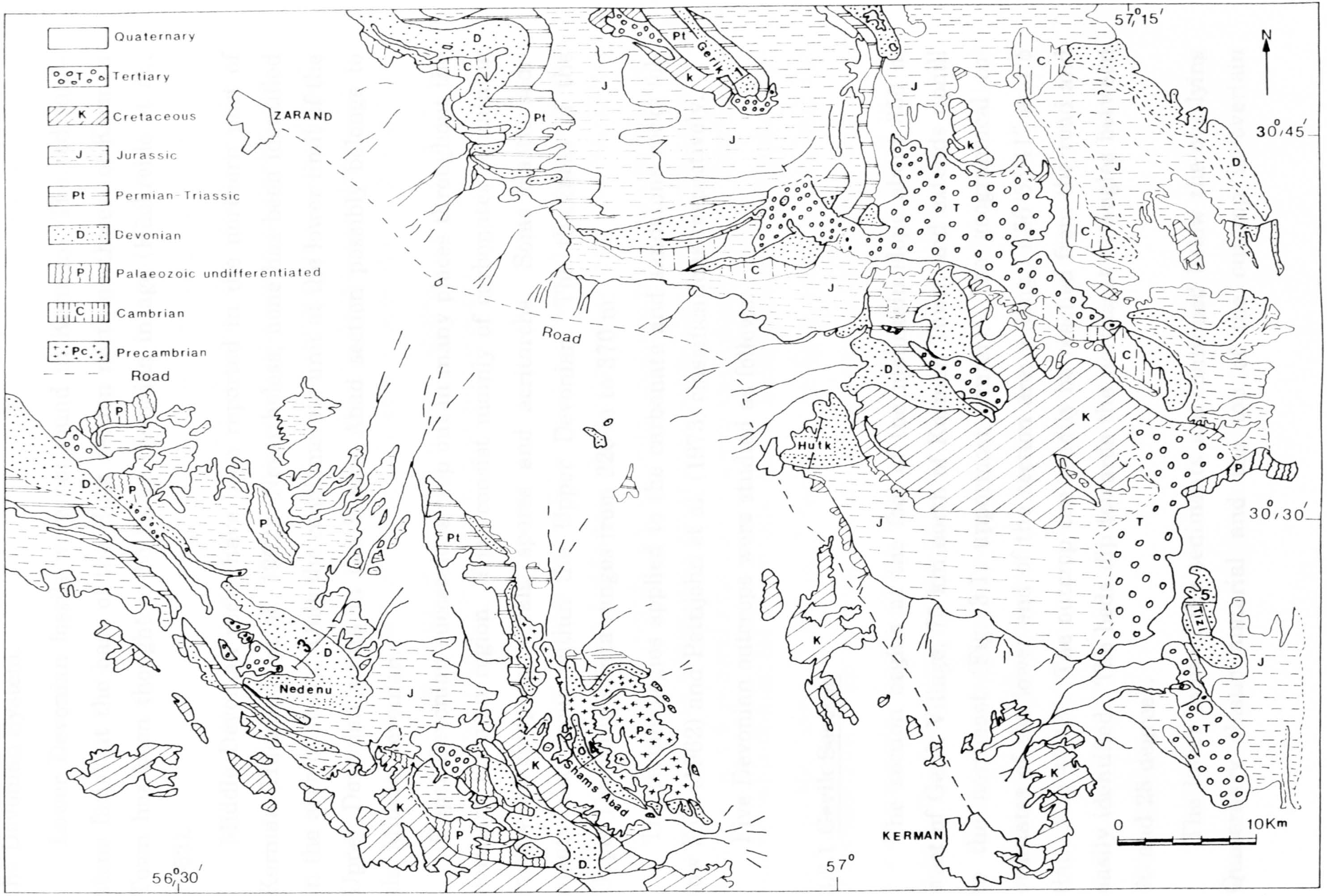


Figure 3.1- Geological map of the northern Kerman Region and location of the study area.(after Hückriede et al. ,1962 with some changes).

Later, Dimitrijevic (1973) assigned ?Late Silurian-?Early Carboniferous age to the strata exposed in the Shams Abad and Nedenu sections, northwest Kerman. However, it is now apparent that they all belong to the Devonian System.

Lower Devonian fossils were not found in Kerman. The red sandstone facies at the base of the Hutk section north-northwest of Kerman Town has been thought to be Early Devonian in age (Hückreide et al., 1962).

Middle Devonian rocks have been reported in the northern part of Kerman (Hückreide et al., 1962). Nevertheless, none has been identified in the area of study. Only the conglomerate unit at the lower limit of the Upper Devonian strata in the Shams Abad section possibly belongs to the Middle Devonian.

Upper Devonian successions crop out in many places throughout the northern Kerman region. They consist mainly of carbonates containing mostly brachiopods, corals, spores and acritarchs. Some clastic sediments also occur within the Upper Devonian. The thickness of the Upper Devonian strata ranges from 220 m to 370 m.

The terminologies applied to the carbonate and sandstone rocks follow Folk (1962) and Pettijohn et al. (1973) classifications respectively.

Five Devonian outcrops were studied as follows:

3.2.1 Gerik Section

The section begins at the foot of the mountain slope about 350 m west of Gerik Village, 75 km north of Kerman Town, and extends uphill to the northeast (Fig. 3.1, uppermost center). The geographical coordinates of the lower end of the section are: γ (long.) E56°53′41″ and ϕ (lat.) N30°47′43″. The outcrop can readily be reached from the road and easily identified. The beds dip towards the northeast at angles between 20 and 25 degrees.

The lower limit of the sediments are continued below the overlying Quaternary clastic material and the top of the outcrop is overlain unconformably by dolomitic limestones and dolomites referred to as Permian-Triassic (Hückreide et al., 1962). The total thickness of the Upper Devonian strata is about 220 m.

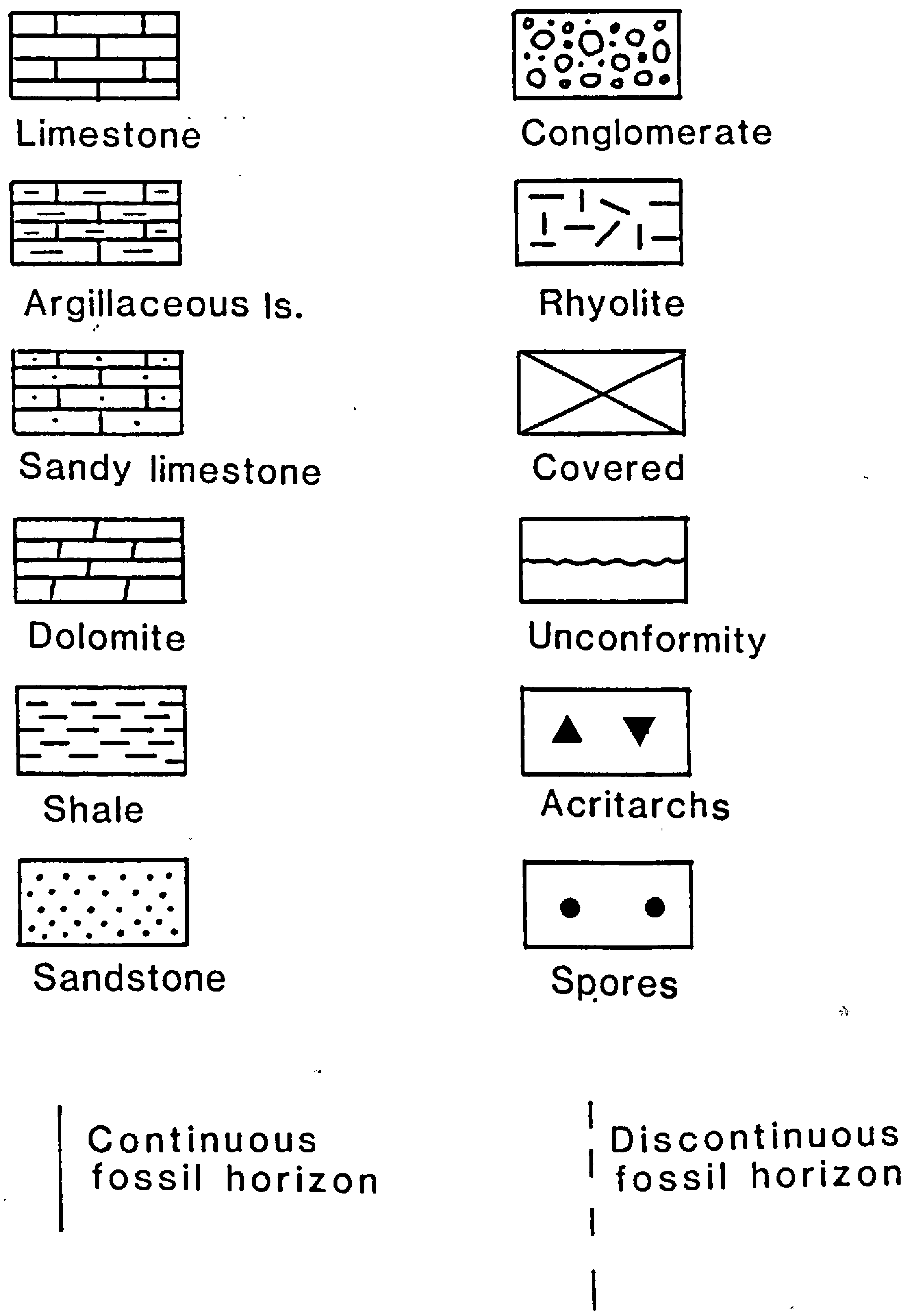
The basal unit of the section consists of about 25 m of medium to thin-bedded, light brown microcrystalline limestone containing brachiopods (Plate 3.5b). The limestone is followed by a 29 m medium to very thin-bedded, medium to coarse-grained white sandstone. The quartz grains are rounded and moderately sorted; about 10% of the rock volume is made of rock fragments, 4-5% feldspar (arkosic to subarkosic arenite) with 7 to 10% siliceous and hematite cement. Sedimentary structures were not found in this unit. The sandstone is succeeded by 15 m of thin-bedded green shale interbedded by limestone. Several brachiopod taxa were found within the limestone beds (Fig. 3.2 and Plate 3.5a). The shale contains acritarchs and spores, e.g. *Chomotriletes vedugensis*, suggesting Frasnian marine environment (see Chapter 6 for details).

The shale unit passes into a 25 m thick succession of reddish brown to light brown, medium bedded biomicritic limestone and dolomite (Plate 3.11a). The faunas include brachiopods, gastropods, ostracods and crinoids. Plate 3.1a shows medium to thin-bedded limestone with erosional surface. A 4-6 m coral unit occurs above the dolomite beds. *Disphyllum caespitosum* dominates the faunas and is accompanied by numerous solitary corals. Some of the coral fossils have been found throughout the Frasnian strata up to level 150 m. Brachiopods, gastropods and bryozoans were also found within the coral community (see Plates 3.1b and 3.2a). The fossils are preserved in a muddy limestone lithofacies.

The strata overlying the coral unit are medium-bedded fossiliferous argillaceous grey limestone and shale, reaching a thickness of about 55 m. Brachiopods dominate the faunas; in addition a few gastropods, bryozoans and crinoids (Plate 3.2b) with some coral fragments were found in this sequence.

Based on the extinction of the Frasnian fauna and the appearance of the Famennian brachiopods, the boundary between the two stages can be

Explanation of the symbols used in figures 6.1–6.4.



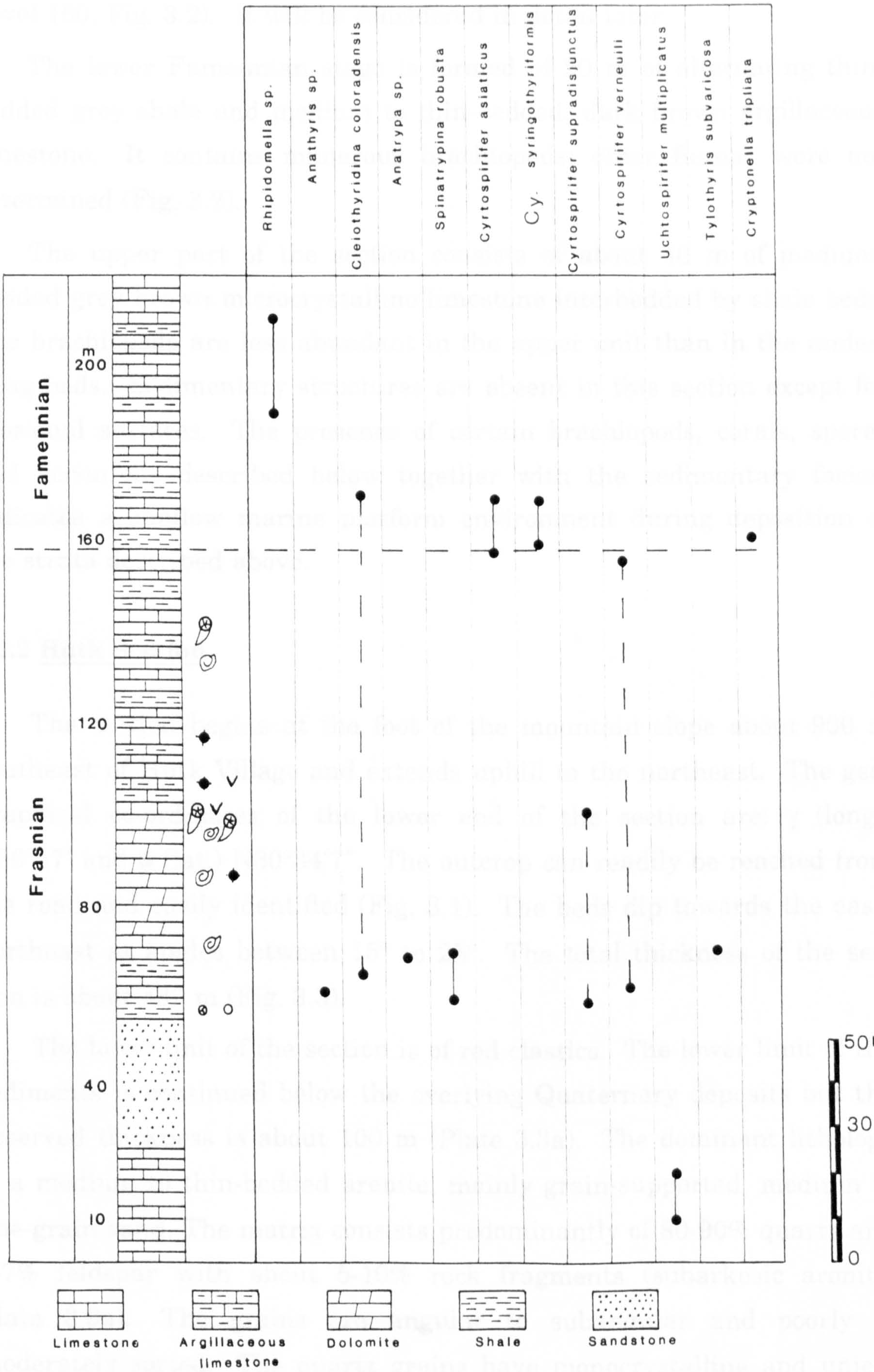


Figure 3.2- Stratigraphical sequence and brachiopod range chart of Gerik section.

established at the lower limit of the shale beds above the carbonate unit (level 160, Fig. 3.2). It will be considered in detail later.

The lower Famennian stage is formed of 20 m of alternating thin-bedded grey shale and medium to thin-bedded, dark brown argillaceous limestone. It contains numerous brachiopods; other faunas were not determined (Fig. 3.2).

The upper part of the section consists of about 40 m of medium-bedded grey brown microcrystalline limestone interbedded by shale beds. The brachiopods are less abundant in the upper unit than in the underlying beds. Sedimentary structures are absent in this section except for erosional surfaces. The presence of certain brachiopods, corals, spores and acritarchs described below together with the sedimentary facies, indicates a shallow marine platform environment during deposition of the strata described above.

3.2.2 Hutk Section

The section begins at the foot of the mountain slope about 900 m southeast of Hutk Village and extends uphill to the northeast. The geographical co-ordinates of the lower end of the section are: γ (long.) E56°57′ and ϕ (lat.) N30°34′7″. The outcrop can readily be reached from the road and easily identified (Fig. 3.1). The beds dip towards the east-northeast at angles between 15° to 25°. The total thickness of the section is about 480 m (Fig. 3.3).

The lower unit of the section is of red clastics. The lower limit of the sediments is continued below the overlying Quaternary deposits but the observed thickness is about 100 m (Plate 3.3a). The dominant lithology is a medium to thin-bedded arenite, mainly grain-supported, medium to fine-grain sand. The matrix consists predominantly of 80-90% quartz and 5-7% feldspar with about 5-10% rock fragments (subarkosic arenite, Plate 3.9a). The grains are angular to subangular and poorly to moderately sorted. The quartz grains have monocrystalline and uniextinction, possibly indicating an igneous source. The grains are well

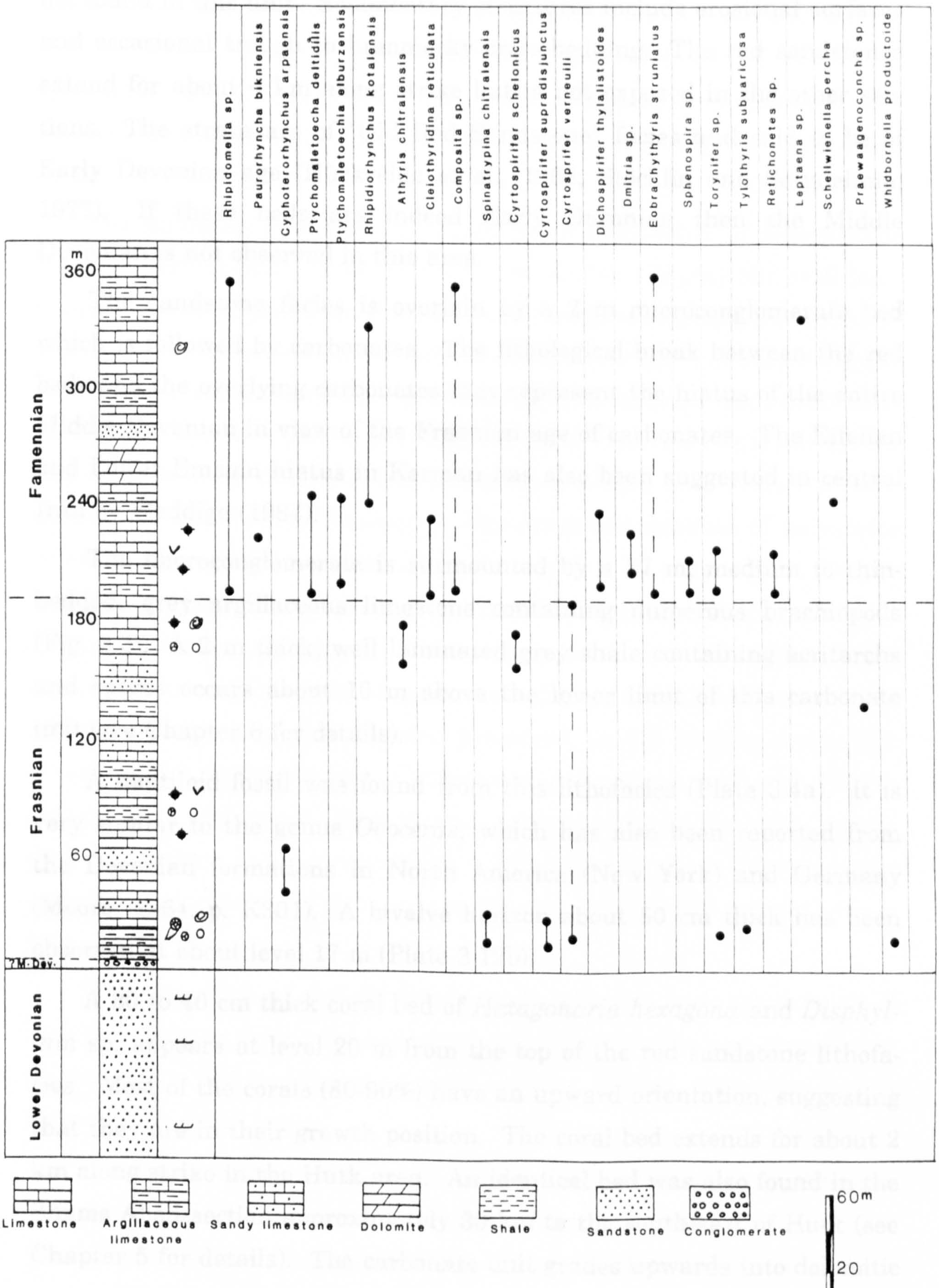


Figure33 Stratigraphical sequence and brachiopod range chart of Hutk section.

packed with little cement (10-12% of the rock volume). The cement is calcite and dolomite, together with a large quantity (about 30% cement) of iron oxide, which gives a characteristic red appearance. Fossils were not found in this unit. Sedimentary structures include erosional surfaces and occasional trough to hummocky cross-bedding. The red sandstones extend for about 4 km along strike but is not exposed in the other sections. The strata are of "Old Red Sandstone" facies and said to be of Early Devonian age (Hückreide et al., 1962; Stöcklin and Setudehnia, 1977). If these beds are indeed Early Devonian then the Middle Devonian is not observed in this area.

The sandstone facies is overlain by a 2 m microconglomerate bed which is followed by carbonates. The lithological break between the red beds and the overlying carbonates may represent the hiatus of the entire Middle Devonian in view of the Frasnian age of carbonates. The Eifelian and Lower Emsian hiatus in Kerman has also been suggested in central Iran by Weddige (1984).

The microconglomerate is surmounted by a 27 m, medium to thin-bedded, grey argillaceous limestone containing numerous brachiopods (Fig. 3.3). A 2 m thick, well laminated grey shale containing acritarchs and spores occurs about 10 m above the lower limit of this carbonate unit (see Chapter 6 for details).

A nautiloid fossil was found from this lithofacies (Plate 3.4a). It is very similar to the genus *Ovoceras*, which has also been reported from the Devonian formations in North America (New York) and Germany (Moore, 1964, p. K301). A bivalve horizon about 50 cm thick has been observed at about level 17 m (Plate 3.12b).

A 30 to 40 cm thick coral bed of *Hexagonaria hexagona* and *Disphyllum* sp. appears at level 20 m from the top of the red sandstone lithofacies. Most of the corals (80-90%) have an upward orientation, suggesting that they are in their growth position. The coral bed extends for about 2 km along strike in the Hutk area. An identical bed was also found in the Shams Abad section approximately 30 km to the southwest of Hutk (see Chapter 5 for details). The carbonate unit grades upwards into dolomitic limestone with a decreasing number of brachiopods.

The carbonate facies is succeeded by 46 m of sandstone and dolomite. The sandstone is an arkosic arenite, reddish white in colour; it is thick to very thick-bedded, fine sand, angular to subangular and well to medium sorted. No sedimentary structures were determined within the sandstone. The dolomite is reddish brown, medium to thin-bedded and microcrystalline, containing about 10% bioclasts and 7 to 10% fine-grain sand.

The sandstones pass into a succession of about 90 m of intermittent shale, carbonate and sandstone beds. The shales are grey and well laminated. Four samples from the successive shale beds (levels 80, 105, 135 and 165 m) were processed for palynological materials, but only the samples from levels 80 and 165 m were found to contain numerous acritarchs and spores. Levels 105 and 135 m are barren of palynomorphs (see Chapter 6 for details). The carbonate is a light grey to dark brown, medium to thin-bedded limestone. The limestone consists of pelsparite (Plate 3.10a); peloids are small and irregular in shape. The faunas include brachiopods, crinoids, bryozoans and tentaculites (Plate 3.3b). The sandstones are arkosic to subarkosic arenite, thick-bedded, light grey, medium to fine-grain, angular to subangular and well sorted. No sedimentary structures have been preserved on the surface rocks. The presence of brachiopods (e.g. *Cyphoterorhynchus arpaensis* and *Athyris chitralensis*) and corals (*Hexagonaria hexagonum*) together with spores and acritarchs (e.g. *Ancyrospora carnavonensis* and *Chomotriletes vedugensis*) indicate a Frasnian age for this level (0-190 m) of the section.

The extinction of certain brachiopods and the first appearance of new taxa help to fix the boundary between the Frasnian and Famennian at the base of the argillaceous limestone (level 190 m). This boundary is discussed in detail later.

The Famennian strata begin with thin-bedded grey argillaceous limestone, reaching a thickness of about 16 m. Eleven brachiopod taxa were found within this facies (Fig. 3.3 and Plate 3.5c). A sudden increase in brachiopod debris was found in this unit and could be seen along strike. This is considered to be due to a marked increase in the numbers of brachiopods present. Sedimentary reworking may have played an important role in the concentration of the shells (Plate 3.12a).

The bioclastic limestone unit is followed by 18 m of thick-bedded, light brown fossiliferous limestone. This unit is succeeded by 15 m of medium to thin-bedded, light grey argillaceous limestone containing numerous brachiopods with some crinoids (Plate 3.4b) and bryozoans (Plate 3.2c). The specimen is similar to the genus *Polypora* from the Upper Devonian formations in Chitral and Pamirs (Reed, 1922, p. 28).

The lithofacies passes into a 30 m succession of medium to thick-bedded brown dolomite, sandstone, limestone and shale. The sandstone is formed of medium to thin-bedded white arkosic arenite. The limestone beds consist of thin-bedded dark brown to grey biomicrite. The limestone contains cephalopod fossils (Plate 3.2d), possibly *Ormoceras* (Stockes, 1840, in Moore, 1964). The shale is green grey in colour and well laminated.

The upper unit within the outcrop is composed of medium to thick-bedded dark brown limestone. It is mainly composed of intraoomicrite (Plate 3.10b). Some ooliths have detrital quartz nuclei. The clasts are fine sand to silt size quartz and make up 20 to 25% of the rock volume. The number of faunas decreases towards the top of the section.

It is worth noting that several fragments of arthodires, e.g. *Eastmanosteus* and *Holonema*, have been reported from the Devonian formations in the Hutk section (Golshani and Janvier, 1974). The fragments are associated with the coral horizon and indicate a Late Devonian age.

Overlying the Famennian strata to the northeast of Hutk is a section of dolomitic limestone and dolomite barren of macrofossils. The upper boundary of the Famennian cannot be established locally.

3.2.3 Nedenu Section

The section begins at the foot of the mountain slope immediately west of Nedenu Farm and extends uphill to the southwest. The geographical co-ordinates of the lower end of the section are: γ (long.) E56°34′43″ and ϕ (lat.) N30°27′37″. The location can readily be reached from the road and easily identified (Fig. 3.1). The beds dip towards the southwest at angles between 20° and 25°. The total thickness of the Devonian rocks is about 480 m. The Devonian rocks have been thrust over the Jurassic shales (Plate 3.6a).

The fossils are not well preserved. Only 21 brachiopod specimens were found suggesting a possible Devonian age (Fig. 3.4). Six samples from the successive shale beds were processed for spores and acritarchs (levels 15, 110, 120, 130, 305 and 430 m), but no palynomorphs were found. Miospores and acritarchs are usually well preserved in fine-grained rocks; nevertheless, well washed sands, recrystallized limestones and reoxidized sediments are unsuitable and commonly barren of these microfossils. Temperatures rising to about 250°C will change acritarchs' colour from pale yellowish green to grey-black and their composition converges to graphite. However, they cannot survive beyond that point (Downie, 1984). Thus palynomorphs are usually difficult to obtain from highly deformed sediments. It is possible that the rocks in this section were heated to about 250° or slightly higher but the temperature was insufficient to cause rock metamorphism. Alternatively, the flora may not have been deposited in this area, which is unlikely to be the case.

Three lithofacies are prominent in this outcrop:

a. Sandstones: Four sandstone units occur through the lower part of the section (Fig. 3.4). They consist mainly of medium to thin-bedded, pink to white, medium to coarse, subangular to subrounded and poorly sorted sand grains. About 75-80% of the rock volume is formed of quartz grains, 5-10% rock fragments, and less than 5% feldspar. They have been classified as arkosic to subarkosic arenites. The cement is mainly dolomite

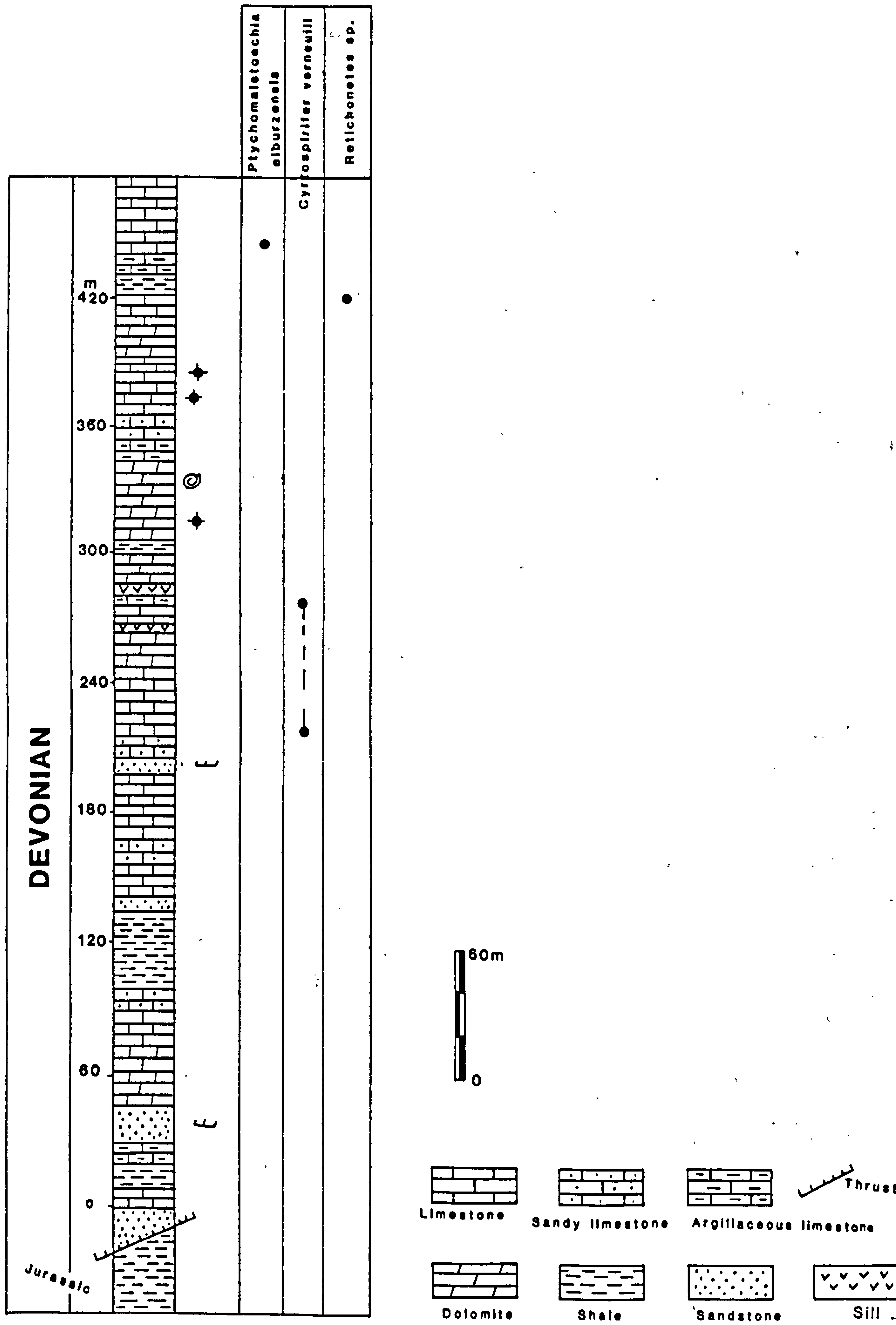


Figure 3-4- Stratigraphical sequence and brachiopod range chart of Nedenu section.

with hematite making up approximately 10% of the rock volume. Sedimentary structures include small scale cross laminae (Plate 3.6b).

b. Carbonate lithofacies: The facies consist of medium to thin-bedded, reddish to light brown, mainly microcrystalline calcite (micrite). The limestones from the lower part of the section contain about 5% fine-grain sand. The beds within the upper part of the outcrop have fragments of brachiopods and crinoids.

c. Shales: The shales are thinly laminated, grey to green, and fissile.

Besides the sedimentary facies two basalt sills also crop out at about 268 m and 286 m above the base of the section (Fig. 3.4). Each sill has a thickness of 3 m. No contact metamorphism was observed. It is likely that the basalt was not hot enough to metamorphose its neighboring rocks.

3.2.4 Shams Abad Section

The section begins at the foot of the eastern side of the Zangu Mountain slope, approximately 1500 m northeast of Shams Abad Village (Fig. 3.1). The geographical co-ordinates of the lower end of the section are: γ (long.) E56°47′50″ and ϕ (lat.) N30°22′30″. The outcrop can readily be reached from the road and is easily identified. The beds dip towards the west at angles between 15° and 20°. The total thickness of the Devonian rocks is about 360 m (Fig. 3.5).

The Devonian strata unconformably overlie the "Infracambrian" rocks (Plate 3.7a); they are unconformably overlain by the Jurassic shales.

The lower unit of the section is formed of 10-30 m of red shale and 20-56 m of conglomerate; these rocks are discussed in Chapter 7. The conglomerate is followed by sandstone and gradually passes into sandy limestone. Since brachiopods, corals, acritarchs and

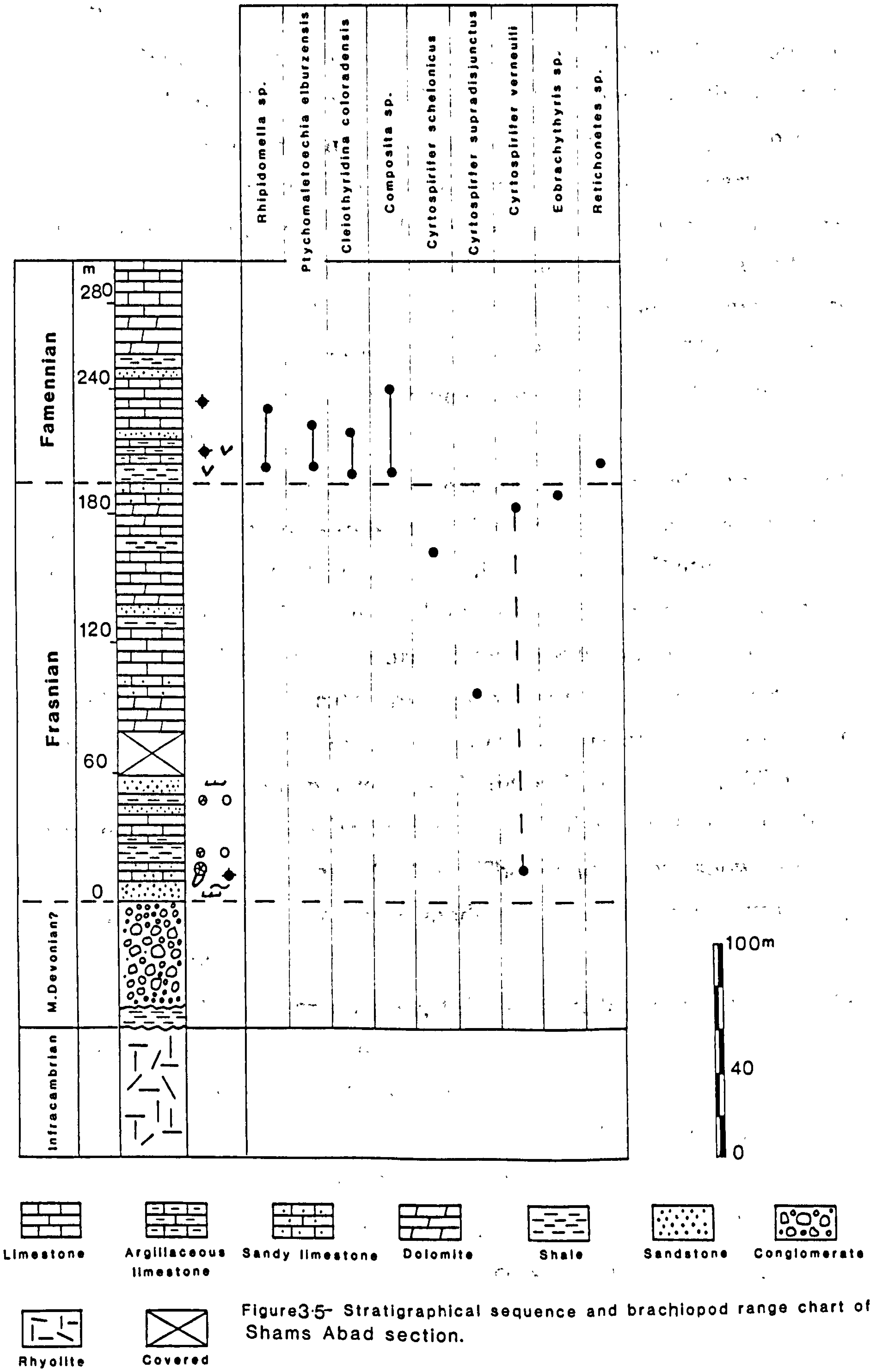


Figure3·5- Stratigraphical sequence and brachiopod range chart of Shams Abad section.

spores indicated Frasnian age for the strata directly overlying the conglomerate unit, this rock unit possibly belongs to the Middle Devonian.

Overlying the conglomerate unit is about 12 m of medium to thin-bedded, reddish white sandstone. The dominant lithology is medium to fine-grain sand, subangular and moderately to poorly sorted. The matrix consists predominantly of 80-85% quartz, 5-7% feldspar and about 10-15% rock fragments (sublitharenite to subarkosic arenite). The cement is mainly composed of silica with a small amount (about 10%) of iron oxide. The cement makes up approximately 10% of the rock volume (Plate 3.9b). The unit contains rare large (sinou-lunate) ripples and hummocky trough cross-laminae (Plate 3.8b).

The sandstone facies is surmounted by 50 m of intermittent carbonates, shales and sandstones. The carbonates consist predominantly of pale brown thin-bedded intrabiomicrite (Plate 3.7b). The intraclasts are 10-15% fine sand and silt-size quartz. The quantity of intraclasts decreases upward. Brachiopods dominate the fauna; in addition, some crinoids are also present. A 40 to 50 cm coral horizon of *Disphyllum* and *Hexagonaria* occurs at level 15 m. The corals are Frasnian in age (see Chapter 5 for details). They are randomly oriented and/or upside down, indicating that they have been transported (Plate 3.11c). The sandstones show similar characteristics with the lower sandstone unit and have hummocky cross laminae.

The shales are green grey, thin-bedded, laminated and fissile. Four samples from the successive shale beds were processed for palynological materials; three samples from level 20, 25 and 50 m contain numerous acritarchs and spores (see Chapter 6 for details). They indicate a Frasnian age for this part of the section.

About 20 m of the section is unexposed. Overlying the detritus interval are 110 m of carbonate successions interbedded by shales and sandstones. The carbonate strata consist mainly of medium to thin-bedded pale grey dolomite and fossiliferous limestone. Brachiopods dominate the faunas; in addition, crinoids are also present. A shale sample from this succession was treated for spores and acritarchs, but no palynomorphs were observed.

Based on the disappearance of some brachiopods and the occurrence of new taxa, the boundary between the Frasnian and Famennian can be established at the base of the shale bed (level 195). It is considered in detail below. Sedimentary structures include erosional surfaces (within the carbonate) and trough to hummocky cross-laminae within the interbedded sandstone (Plate 3.8c).

Famennian strata within the Shams Abad section consist of 105 m of shales, argillaceous limestone, sandstone, limestone and dolomite. The shales are thin-bedded and grey and contain brachiopods and bryozoans (Fig. 3.5). The argillaceous limestone unit is thin-bedded, pale grey and contains numerous brachiopods, crinoids and bryozoans. The sandstone is similar to those described above. The limestone is medium-bedded, grey biomicrite having brachiopods and crinoid fragments (Plates 3.11b and 3.12c).

The upper unit within the outcrop is composed of medium to thick-bedded dark dolomite, pelmicrite (Plate 3.10c) and dolomitic limestone. The number of faunas decreases markedly toward the top of the section.

3.2.5 Tizi Section

The section begins at the foot of the Tizi Mountain, about 22 km northeast of Kerman, and extends uphill to the southeast. The geographical co-ordinates of the lower end of the section are: γ (long.) E57°13′4″ and ϕ (lat.) N30°26′13″. The outcrop can readily be reached from the road and easily identified (Fig. 3.1, lower right).

The beds dip towards the southeast at angles between 15° and 20°. The lower limit of the Devonian strata must occur below the overlying Tertiary clastic materials. The total thickness of the section is about 328 m.

Apart from erosional surfaces, sedimentary structures were not identified in this outcrop.

The lower unit of the section is composed of 60 m of medium to thick-bedded, reddish white sandstone. The dominant lithology consists of 80-85% quartz grains, less than 5% feldspar and approximately 10% rock fragments, and is classified as sublitharenite (Plate 3.9c). It is grain supported, medium to coarse-grain sand, moderately sorted, subangular to subrounded and monocrystalline with normal extinction. The clasts possibly have been derived from igneous source rocks. The cement is calcite and makes up about 10% of the rock volume.

The sandstone unit is followed by a 60 m thick sequence of shale, limestone and sandstone beds. The shales are very thin-bedded, grey and fissile. Seven samples from the shale beds (levels 60, 65, 70, 88, 93, 97 and 135 m) were treated for palynological study. In general, most of the sequences in the Tizi Mountain are barren of fossils, but the shale horizons yield the most abundant Frasnian spores and acritarchs, e.g. *Ancyrospora carnavonensis Chomotriletes vedugensis* (see Chapter 6 for details).

The limestone beds are formed of thin-bedded, dolomitic, sandy (5-70% fine-grain sand), dark brown intramicrite. The sandstone has similar composition and texture to the sandstone unit described above.

The sandstone is surmounted by a succession of 80 m thick dolomite and limestone interbedded by shale. The dolomite is medium to thick-bedded, pale grey and barren of fossils. The limestone is medium to thin-bedded, dark and microcrystalline, having about 5 to 10% fine-grain sand in its composition. The beds contain some brachiopods, e.g. *Cyrtospirifer verneuili* (Fig. 3.6). The interbedded shales are dark green to grey and well laminated. Only one sample (from level 135) which was treated proved to have Frasnian spores and acritarchs (see Chapter 6).

The succession is followed by a 34 m thick-bedded dark cream sandstone. The composition and texture of the unit is similar to the sandstone facies in the lower unit of the section, except for the cement which is mainly dolomite in this unit.

About 90 m of the upper unit of the section consists of thick-bedded dark brown dolomitic limestone and dolomite. These beds lack fossils.

Palaeontological study of the brachiopods, spores and acritarchs confirmed a Late Devonian (Frasnian and Famennian) age for the Tizi section. However, the boundary between the stages is still unknown. Further palynological studies are needed to establish the boundary.

Abundant spores and acritarchs together with scattered brachiopods and clastic materials from this outcrop represent a shallow marine platform condition with a nearby source area.

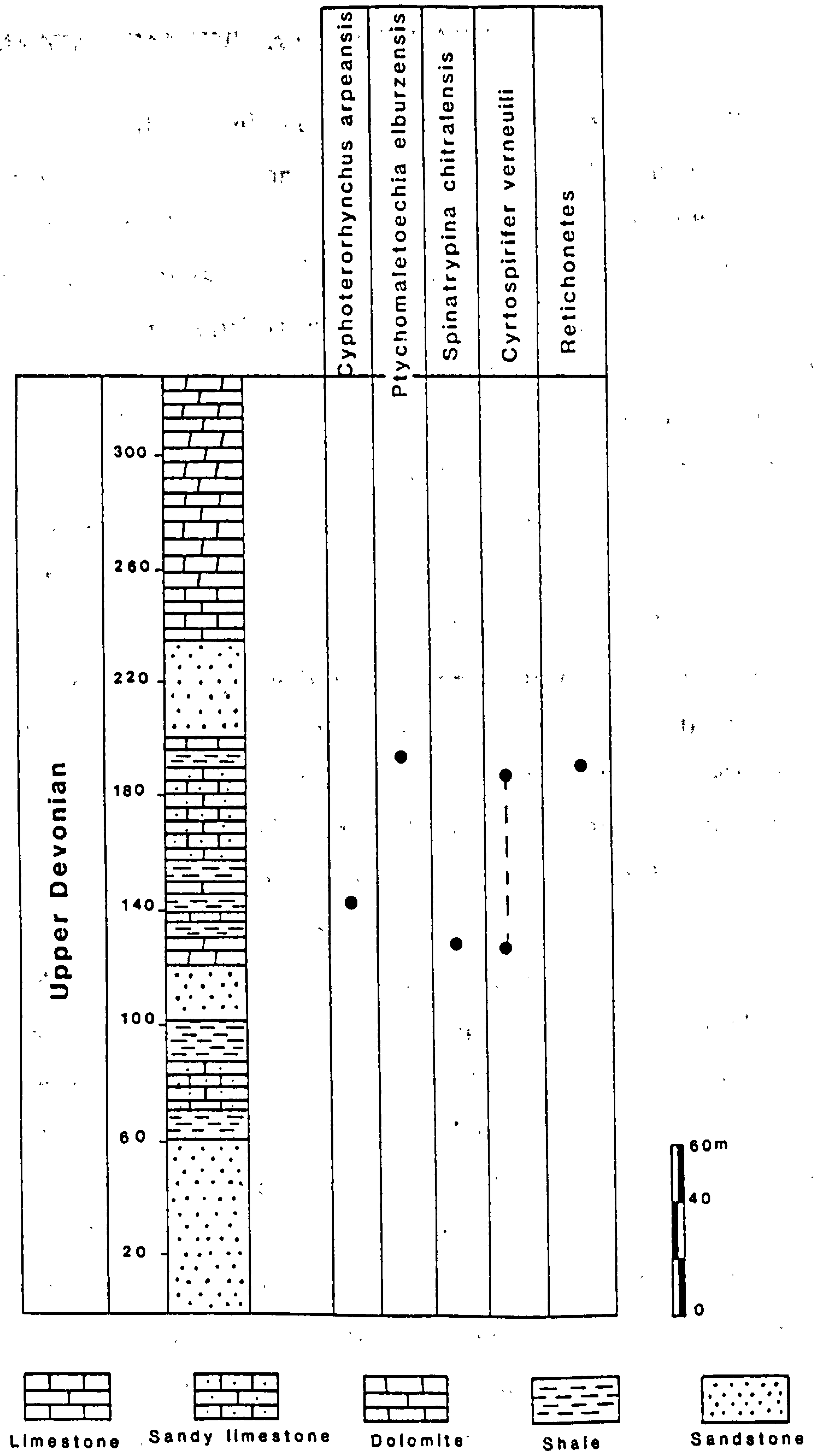


Figure3.6- Stratigraphical sequence and brachiopod range chart of Tizi section.

3.3 FRASNIAN/FAMENNIAN BOUNDARY

The palaeontological record is punctuated by extinctions which have provided a basis for the boundaries in the geological time scale. McLaren (1970, 1982a,b) was the first to suggest that the meteorite impact was the ultimate cause for the global mass killing of shallow water benthos at the Frasnian/Famennian boundary. Since then, the boundary between the two stages has been established on a large geographic scale including extensive parts of Europe, North America, Western Australia and China. The data for proposing the Frasnian/Famennian boundary in Asia have been insufficient hitherto. This study provides some basic information concerning the Frasnian/Famennian boundary in Kerman.

As demonstrated, brachiopods, corals, miospores and acritarchs dominate the fossils within the Devonian succession in the Kerman area. At the end of Frasnian time a number of important brachiopods (13 taxa) became extinct and the Famennian stage was characterized by new faunas (see Figs. 3.2, 3.3 and 3.5). Ten taxa of the spiriferids described below, together with five species of rhynchonellida, e.g. *Ptychomaletoechia elburzensis*, have been found within a vertical interval of about 50 m from the base of the argillaceous limestone (level 190 m) in the Hutk section. Many of them can be found over a wide distance, and also in the Gerik section about 50 km to the north and in the Shams Abad section approximately 25 km to the west (see Figs. 3.2, 3.3 and 3.5). The strata below this level lack the faunas and contain only Frasnian fossils. It is highly probable that the occurrence of these brachiopods in this unit indicates lithofacies control. Sandy limestone facies occurring below level 190 m grade into carbonate and argillaceous limestone in the upper unit. A sudden increase of shell debris at the base of the proposed Famennian in the Hutk section may indicate sea level fluctuation.

The corals described in Chapter 5 are restricted to the Frasnian sediments in the study area. The corals became extinct at the end of the Frasnian stage. A global mass extinction is said to have totally destroyed the complex reef and peri-reef ecosystem that had been growing and developing before the close of the Frasnian (House, 1975).

The Frasnian/Famennian boundary has been established at the lower limit of the argillaceous limestone (level 190 m) in the Hutk section and the base of the black shale beds at level 160 m and level 195 m in the Gerik and Shams Abad sections respectively (see Figs. 3.2, 3.3 and 3.5). Nevertheless, this boundary is not defined in the Tizi and Nedenu sections so far. Further palaeontological study may provide more information for establishing the boundary in these areas.

The Frasnian/Famennian boundary stratotype has been proposed by Bouckaert et al. (1972) at the Hony section in Belgium, using the quantitative variations of acritarchs, e.g. *Micrhystridium* and *Veryhachium ceratioides*. Four of the acritarch genera which were used for the determination of the Frasnian/Famennian boundary in Belgium are also present in the Kerman region. Nevertheless, the palynological samples mainly concern the Frasnian succession. Thus, the delineation of the boundary using miospores and acritarchs obviously could not be achieved with these minimal materials. A quantitative analysis of palynomorphs using samples from directly below and above the proposed limit is needed to fix the boundary.

The Frasnian/Famennian boundary has also been considered in regard to ammonoid and conodont evolution in Europe and North America (see Ziegler and Klapper, 1985, p. 108; House, 1975). In south China the boundary has been established based on the sudden disappearance of certain brachiopods as well as on geochemical anomalies by Jia et al. (1988). Goodfellow et al. (1988) suggested an extinction of shelly benthos at the Frasnian/Famennian boundary in the USA, Belgium, Montagne Noire (France), in Germany and Canada, between the gigas and upper triangularis zones. In the Hutk section the range of most of the Frasnian brachiopods terminates below level 190 m and only new taxa appear in and above this level. The base of this argillaceous limestone bed may approximate to the faunal boundary between the Frasnian and Famennian stages for this area (Fig. 3.3). Its identity can be confirmed in comparison with other outcrops including the Gerik and Shams Abad sections (Figs. 3.2 and 3.5). However, the critical conodonts, i.e. those representing the middle *Palmatolepis triangularis* conodont zone (basal Famennian), have not been found in Kerman, nor have species of the index brachiopod *Pampocilorhynchus* yet been identified as they are in the type section in Belgium.

A geochemical analysis of iridium anomalies using samples from directly below and above the proposed boundary is also suggested to fix the limit.

3.4 CORRELATION OF THE SECTIONS

There have been numerous attempts in the past to employ brachiopods, corals, miospores and acritarchs for intra-basinal and widespread correlations (e.g. Gratsianova et al., 1988). Brachiopods are an especially intractable group for making high-precision stratigraphic alignments over great distances. Thirty-one brachiopod taxa have been defined from Kerman. They are the dominant Devonian faunas and thus are important for correlation in this area.

Several of the following sedimentological and palaeontological factors indicate close correlation for the Upper Devonian strata in Kerman province: a) the lithofacies and sequences are similar (Fig. 3.7), b) the brachiopods are identical throughout most outcrops in northern Kerman, c) the corals also provide a means of correlation for the Frasnian strata in the Gerik, Hutk and Shams Abad sections. The spores and acritarchs, on the other hand, confirm the Frasnian age for most outcrops, but the microfloras have not been found in the Nedenu section.

Finally, the Frasnian and Famennian stages have been confirmed by the brachiopods, corals, spores and acritarchs in the Gerik, Hutk, Shams Abad and Tizi sections. The boundary between these two stages has been proposed at levels 160 m, 190 m and 195 m in the Gerik, Hutk and Shams Abad sections respectively (see also section 3.3 for detail). Only the age of the Nedenu section is uncertain because of the lack of well preserved fossils.

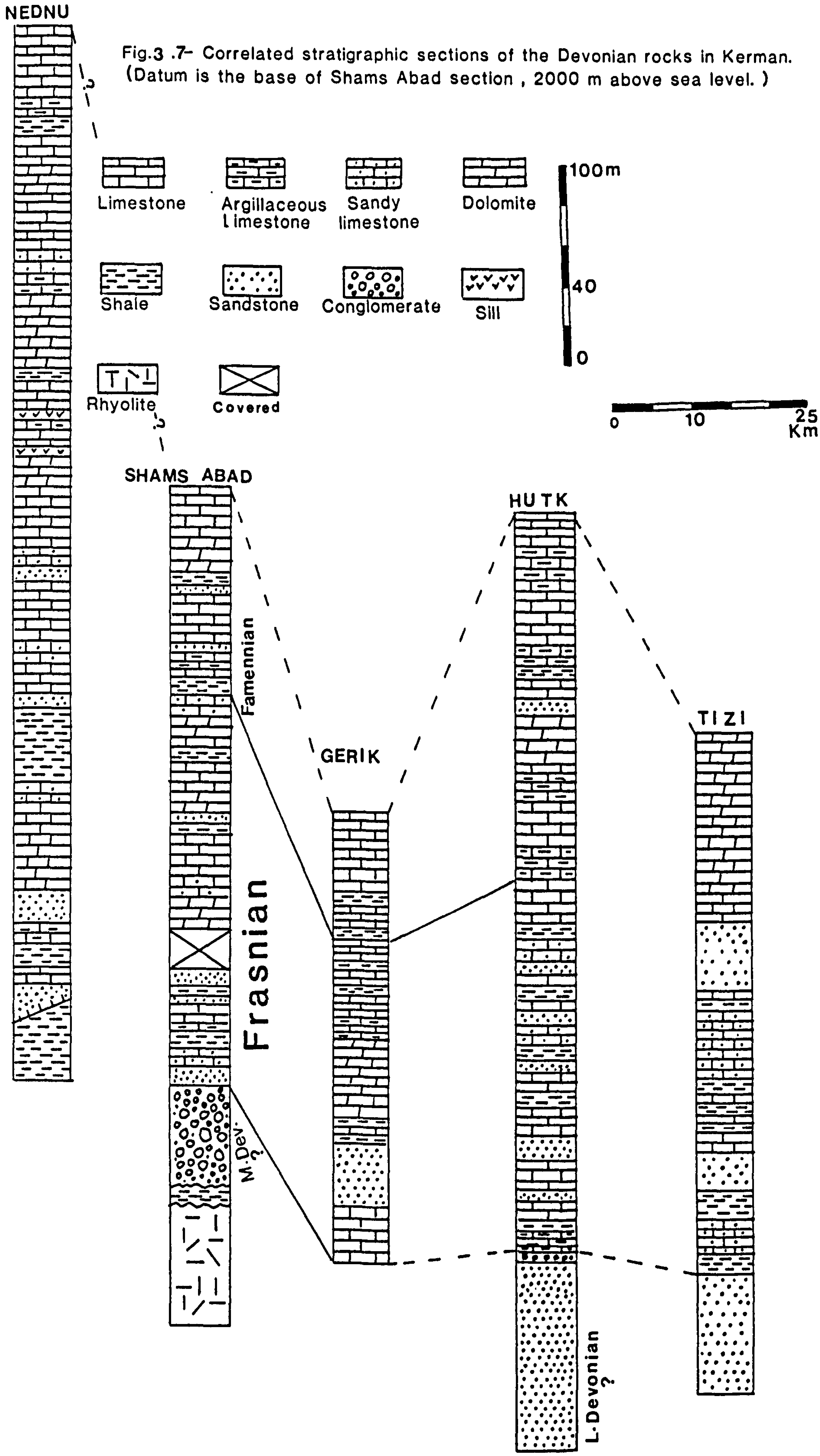


Fig.3 .7- Correlated stratigraphic sections of the Devonian rocks in Kerman. (Datum is the base of Shams Abad section , 2000 m above sea level.)

Plate 3.1

(a) Ten meters thick succession showing medium to thin-bedded limestone with erosional surfaces.
Western limb of Gerik section, level 67-77 m.

(b) Individual gastropods from the coral horizon. All ×2.
Gerik section, level 96-100 m.


A


B
A
B
C
E
F

Plate 3.2

(a) Bryozoans on the bedding surface, collected about 2 m above the base of the coral bed, scale = 2 cm.
Gerik section, sample Gbz10.

(b) Bryozoans (b) and crinoids (c) on the bedding surface. All $\times\frac{1}{2}$.
Gerik section, level 105 m, sample Gbz15.

(c) Bryozoan, possibly *Polypora* (Reed, 1924).
Hutk section, level 210 m, sample Hbz36.

(d) Cephalopod, possibly *Ormoceras* (Stockes, 1840), $\times\frac{3}{4}$.
Hutk section, level 330 m, sample Hc42.

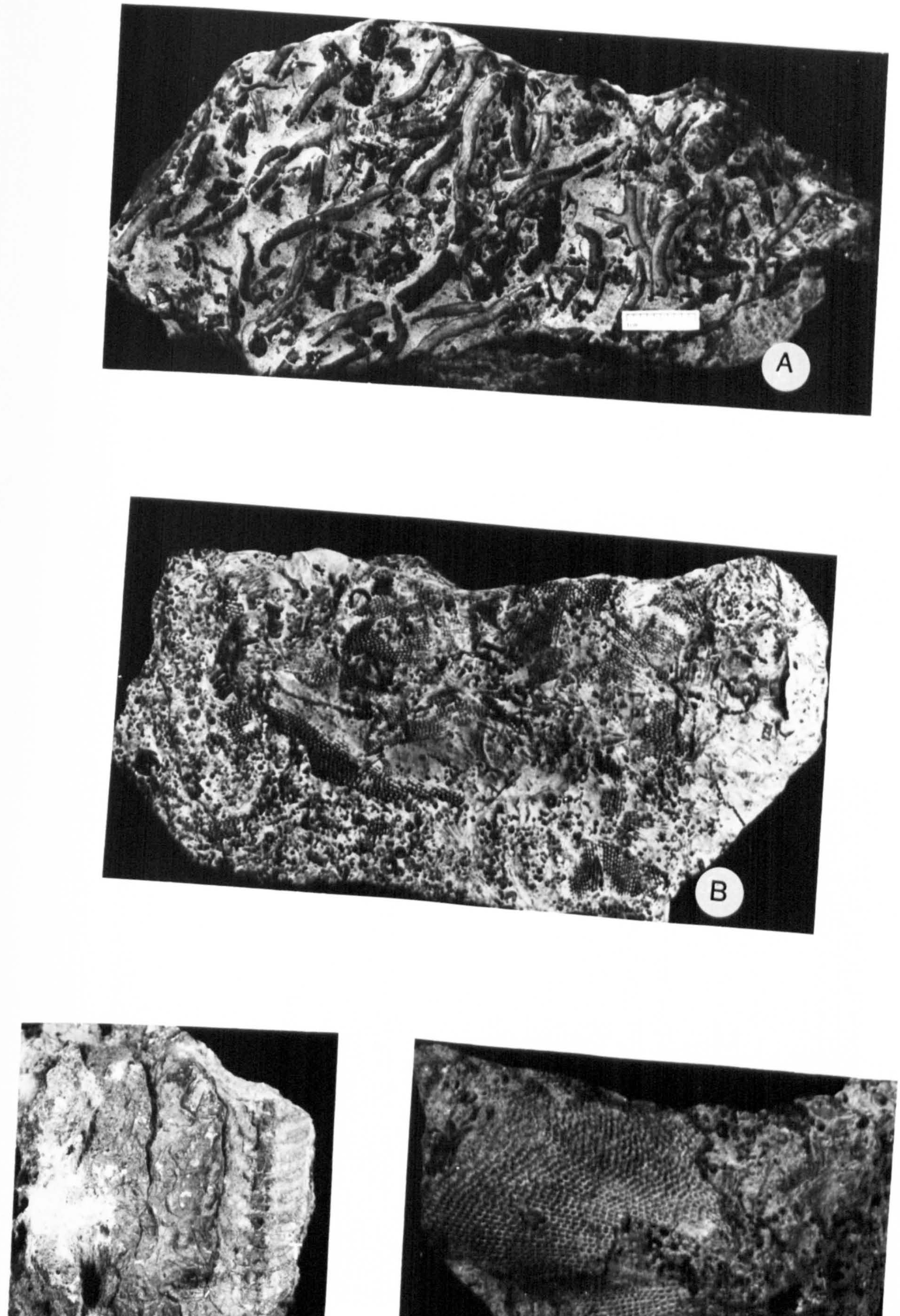

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Plate 3.3

(a) Photograph of western Hutk section immediately east of Hutk village.

Q – Quaternary deposits

Rs – Red sandstone facies

C – Carbonate, sandstone and shale facies

(b) Tentaculite fossils on the bedding surface. ×1.
Hutk section, level 185 m, sample Ht35.


A
c
Rs
Q


B

Plate 3.4

(a) Nautiloid fossil, possibly *Ovoceras* (Flower, 1936). $\times\frac{3}{4}$.
Hutk section, level 25 m, sample HN27.

(b) Crinoid arms on the bedding surface.
Hutk section, level 215 m, sample HC37.

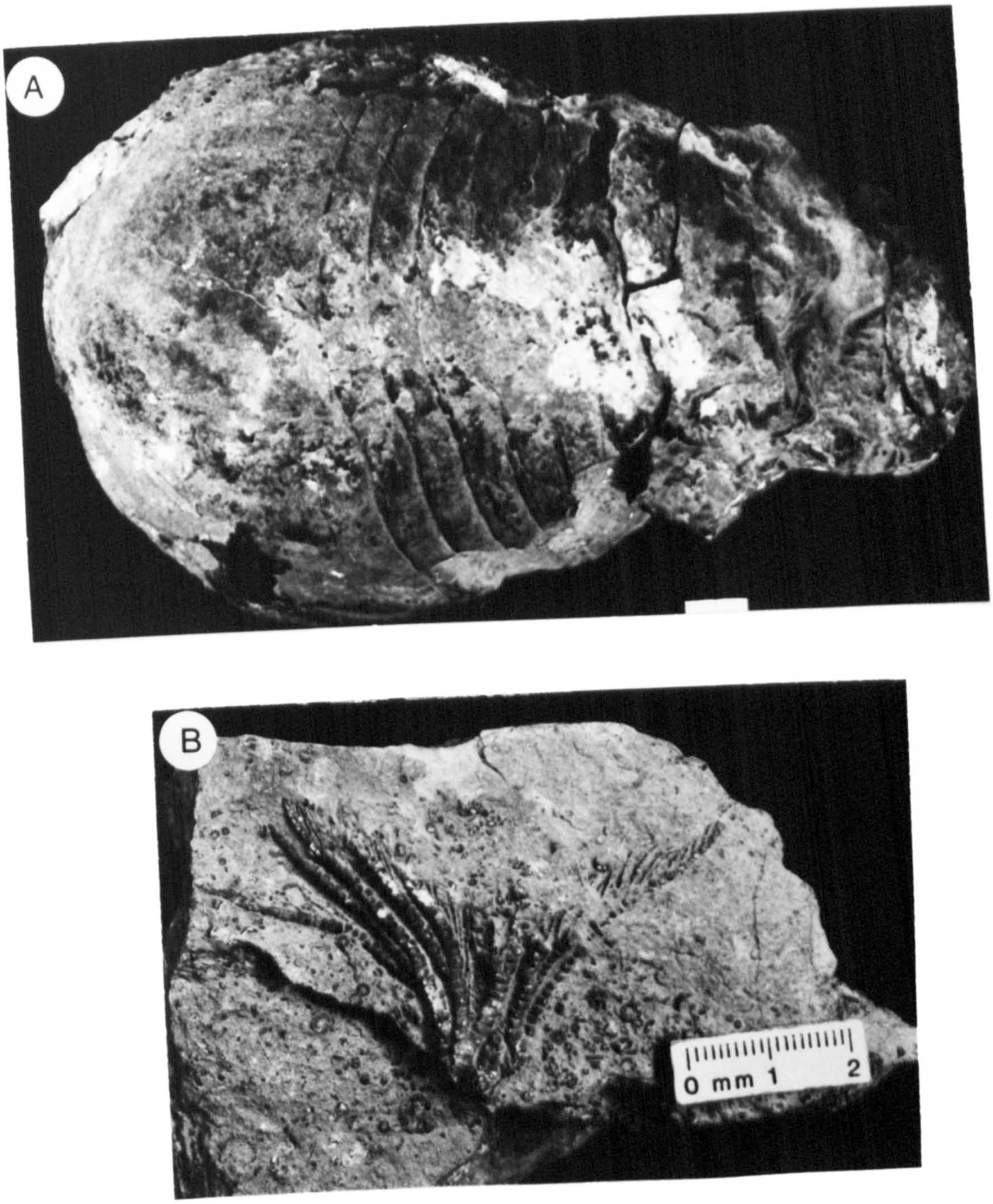
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Plate 3.5

(a) *Cyrtospirifer verneuili* on the bedding surface. ×1.
Gerik section, level 75 m, sample Gb75.

(b) *Uchtospirifer multiplicatus*, oriented randomly. ×1.
Gerik section, level 15 m, sample Gb7.

(c) *Retichonetes* on the bedding surface. $\times\frac{3}{4}$.
Shams Abad section, level 200 m, sample MDH52.

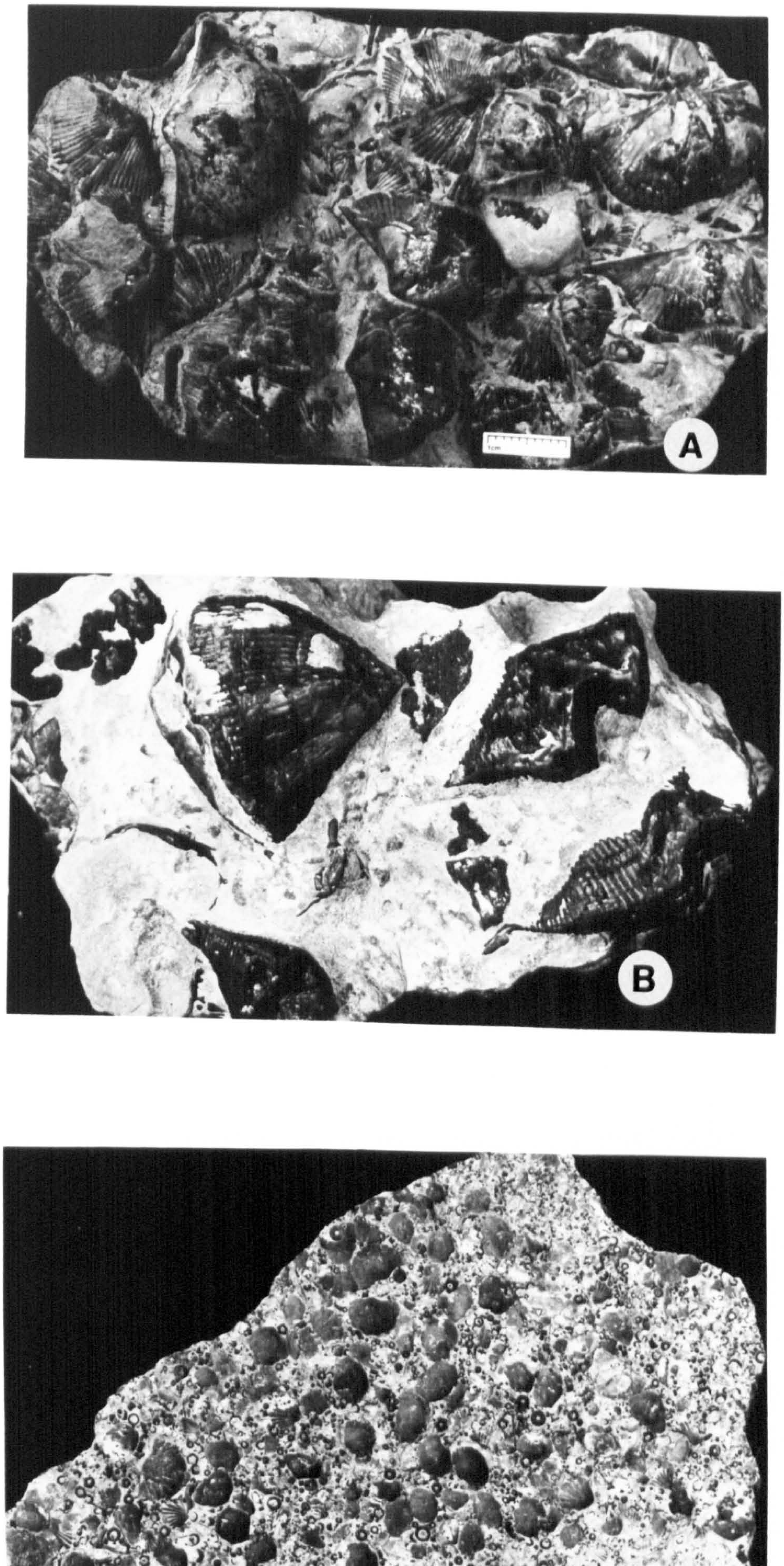
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Plate 3.6

(a) View of the Nedenu outcrop immediately west of Nedenu Farm, illustrating emplacement of the Devonian carbonates on Jurassic shales. Boundary marked by a dashed line.

(b) Co-sets of small scale cross laminae, tabular and wedge sets. Nedenu section, level 204 m.


A


B

Plate 3.7

(a) View of the Shams Abad section, showing angular unconformity between "Infracambrian" (dark colours on right of photograph) and younger strata to the left.

(b) Thin-bedded limestone showing erosional bedding surface. Shams Abad section, level 15 m.

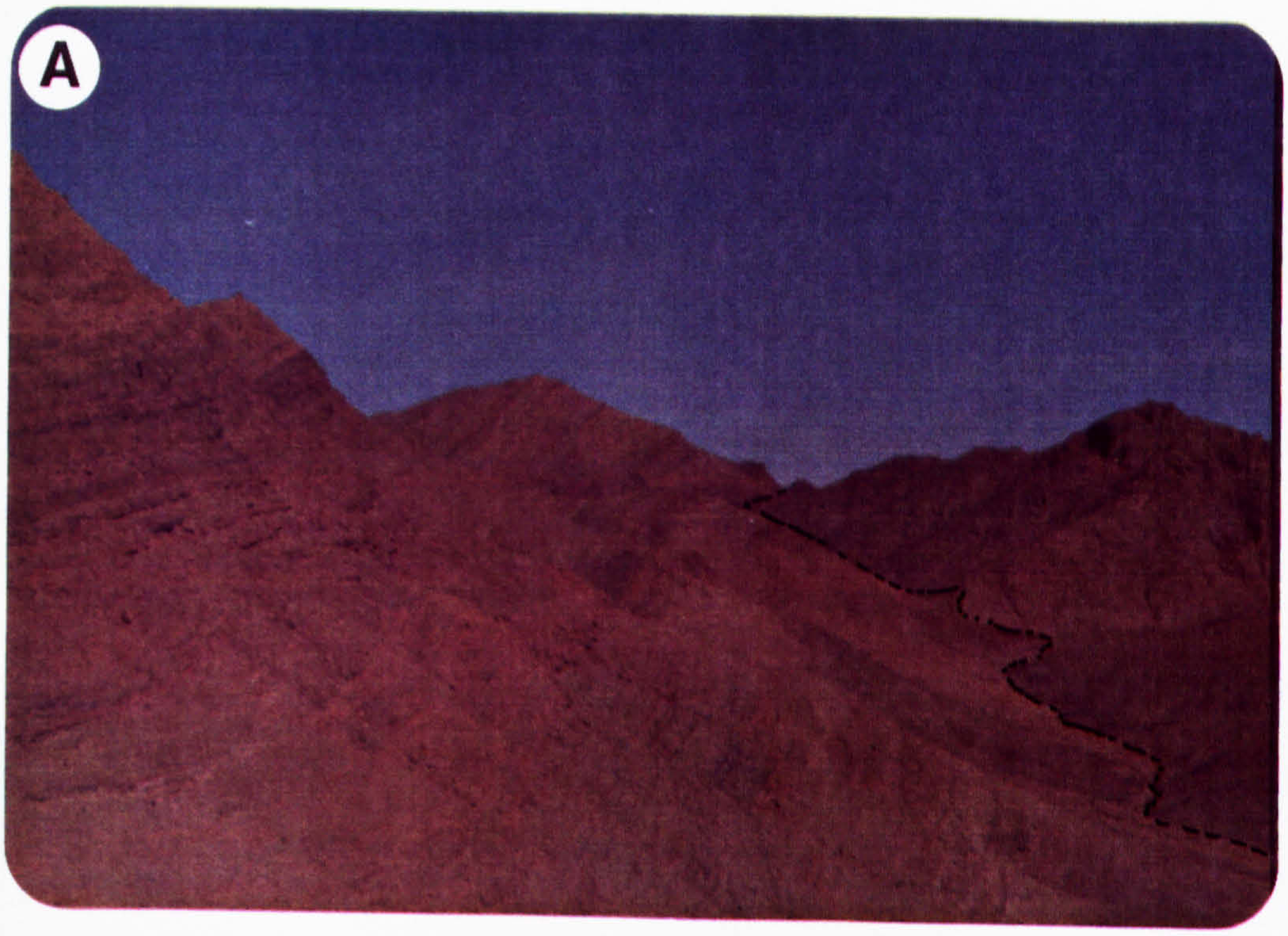
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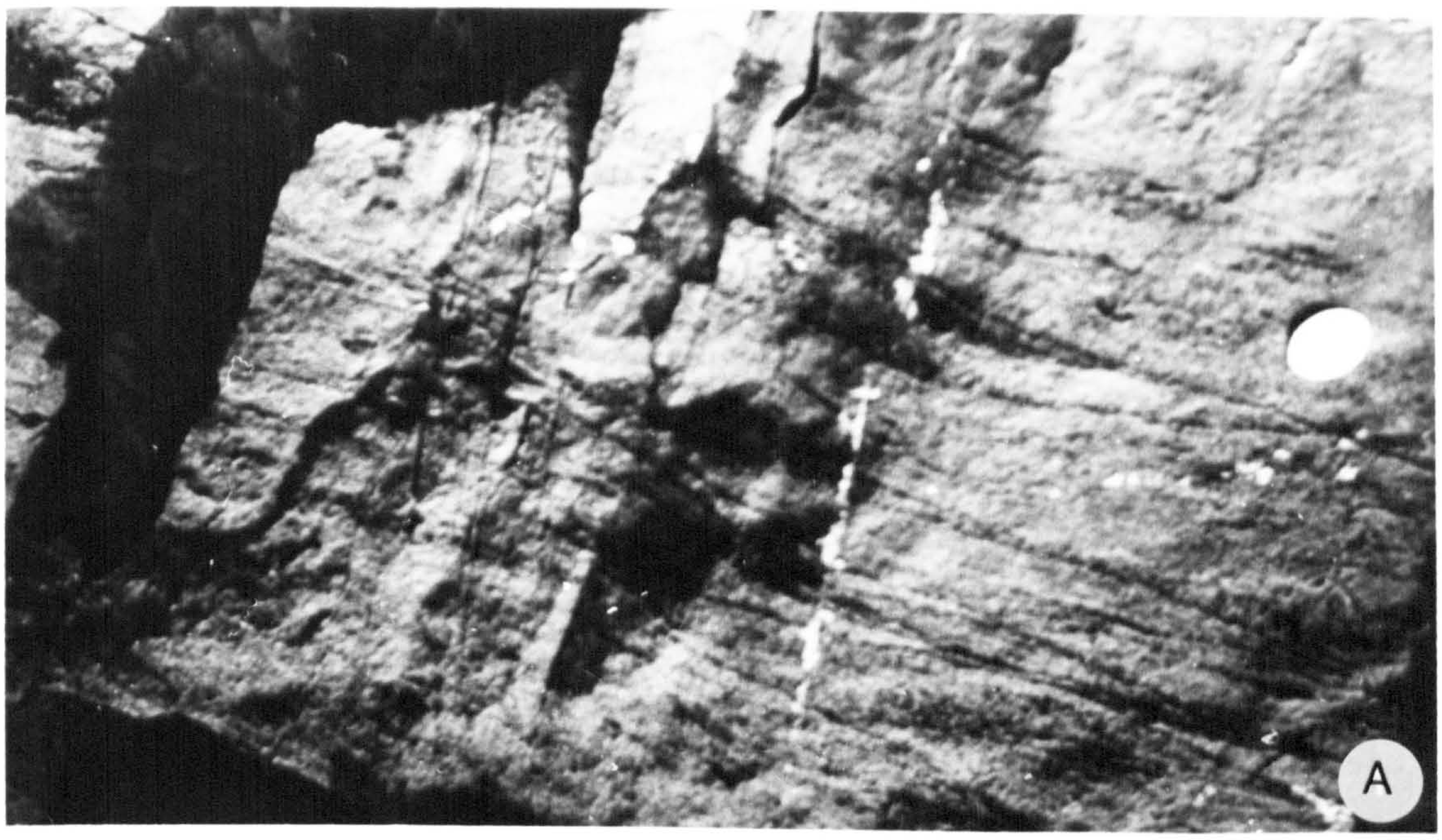
Plate 3.8

(a) Co-set of large trough - hummocky cross laminae from red section 15 m from the base. ×.1.
Hutk section.

(b) Co-set planar-hummocky trough cross laminae, ×.1.
Shams Abad section, level 7 m.

(c) Co-set hummocky trough cross laminae. ×.1.
Shams Abad section, level 54 m.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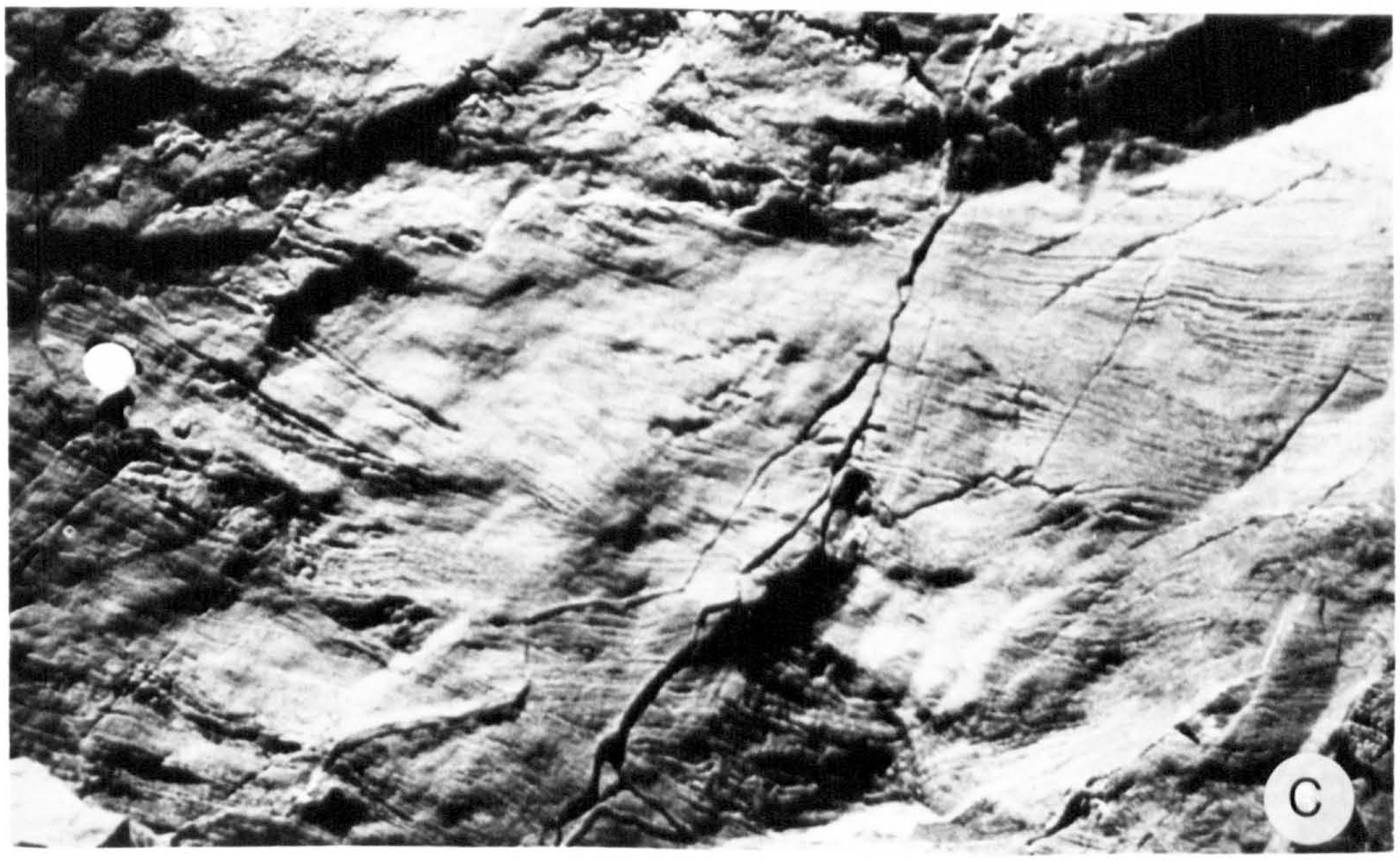
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Plate 3.9

(a) Subarkosic arenite (XPL).
Monocrystalline quartz grains, poorly sorted, angular to subangular, medium sand sized, ×40.
Hutk section, level 80 m.

(b) Sublitharenite (XPL).
Monocrystalline quartz grains, angular to subangular, fine grain sand-sized, about 10% rock fragments, ×40.
Shams Abad section, level 7 m.

(c) Sublitharenite (XPL).
Monocrystalline quartz grains, moderately sorted, subangular to subrounded, fine grain sand sized, ×40.
Tizi section, level 20 m.

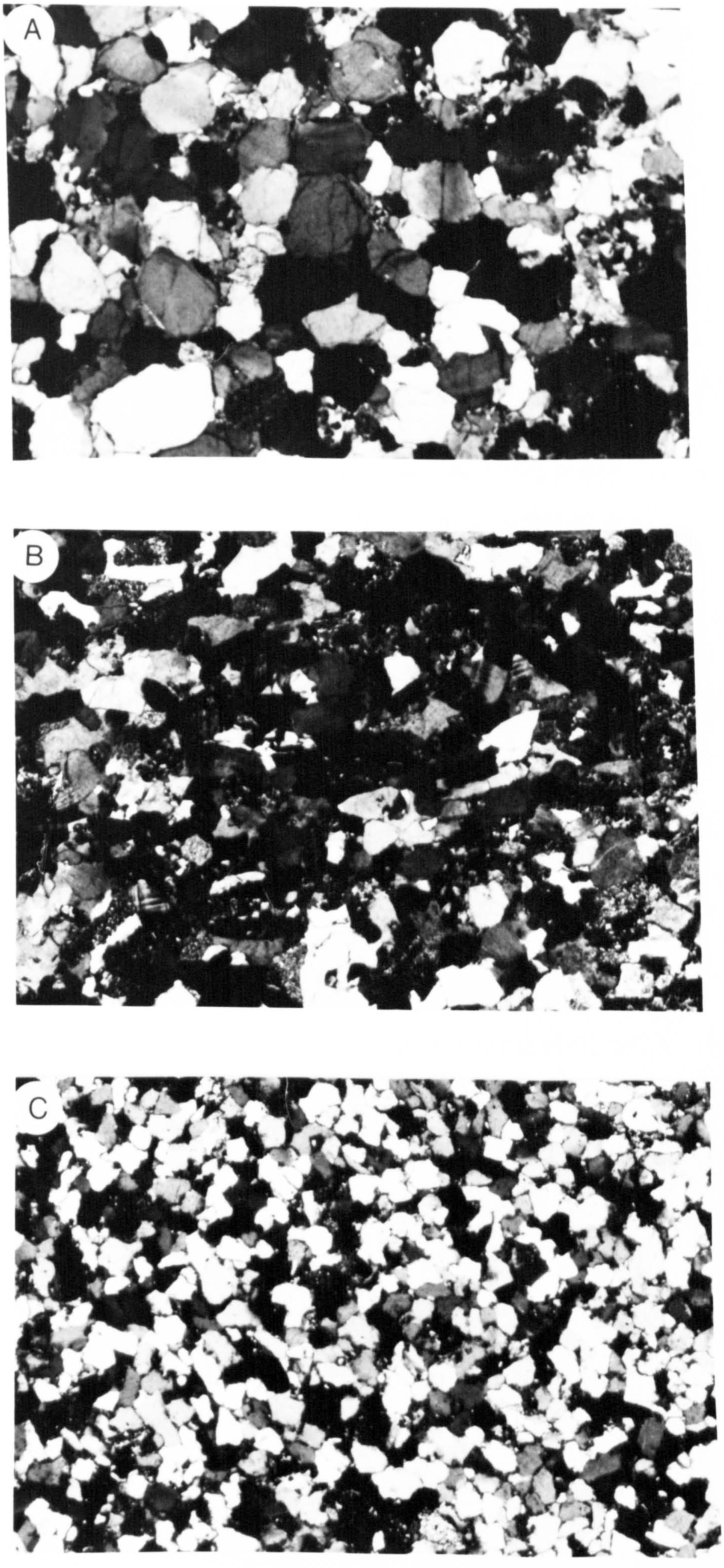
A
B
C

Plate 3.10

(a) Pelsparite (PPL),
containing almost irregular small peloids and sparry clastite (in the lower right of the photograph), ×40.
Hutk section, level 180 m.

(b) Intraoomicrite (PPL),
containing detrital quartz. Some ooliths have detrital quartz nuclei, ×40.
Hutk section, level 330 m.

(c) Pelmicrite (XPL),
containing elliptical peloids averaging about .2 mm in long diameter and broken brachiopod shells, ×40.
Shams Abad section, level 280 m.

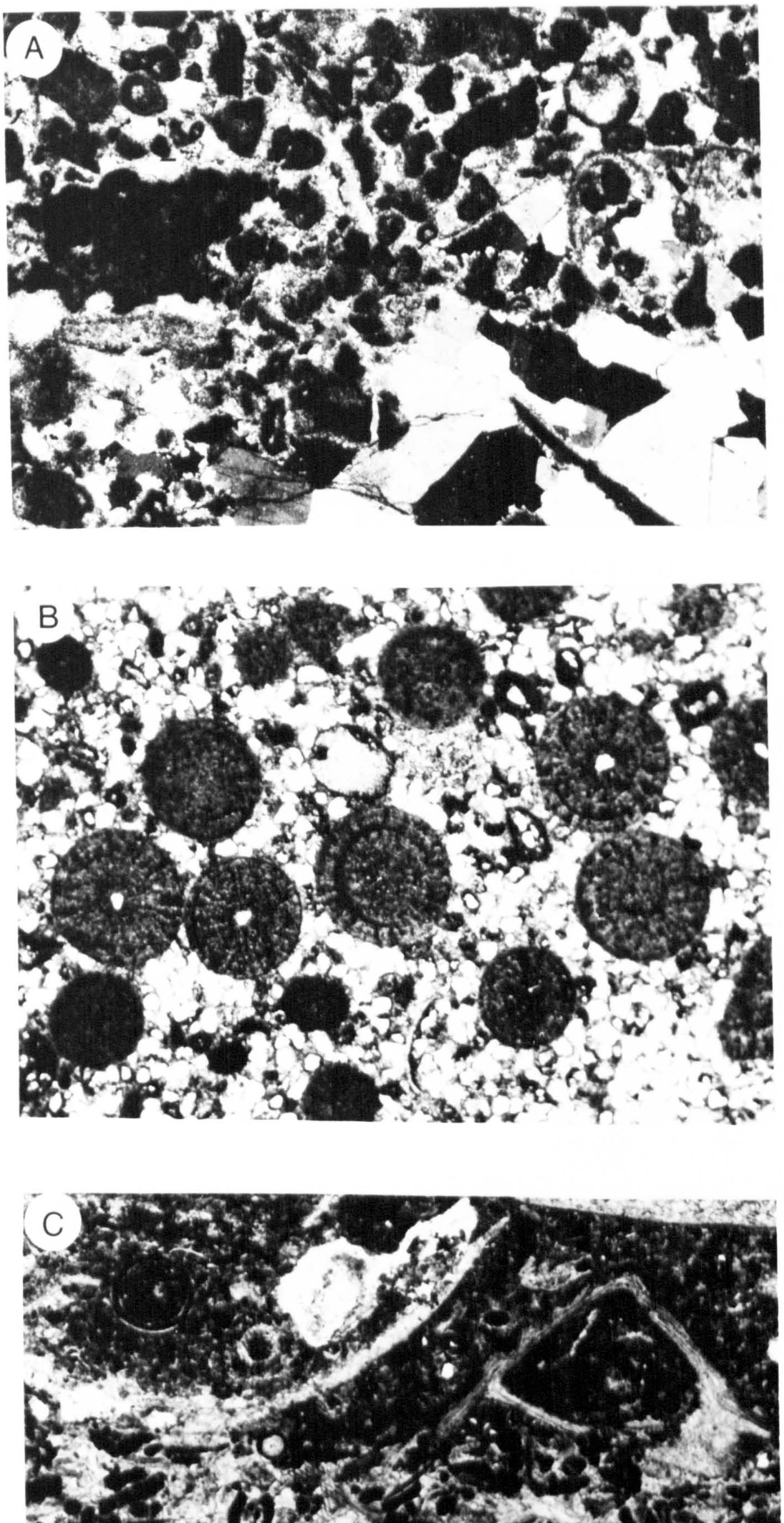
A
B
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Plate 3.11

(a) Biomicrite (PPL).
With large thick-shell gastropods, ×40.
Gerik section, level 70 m.

(b) Biomicrite (PPL).
Showing crinoid (c) and brachiopod (b) shell fragments, ×40.
Shams Abad section, level 234.

(c) Coral horizon (*Hexagonaria*).
Showing upside down orientation.
Shams Abad section, level 15 m.

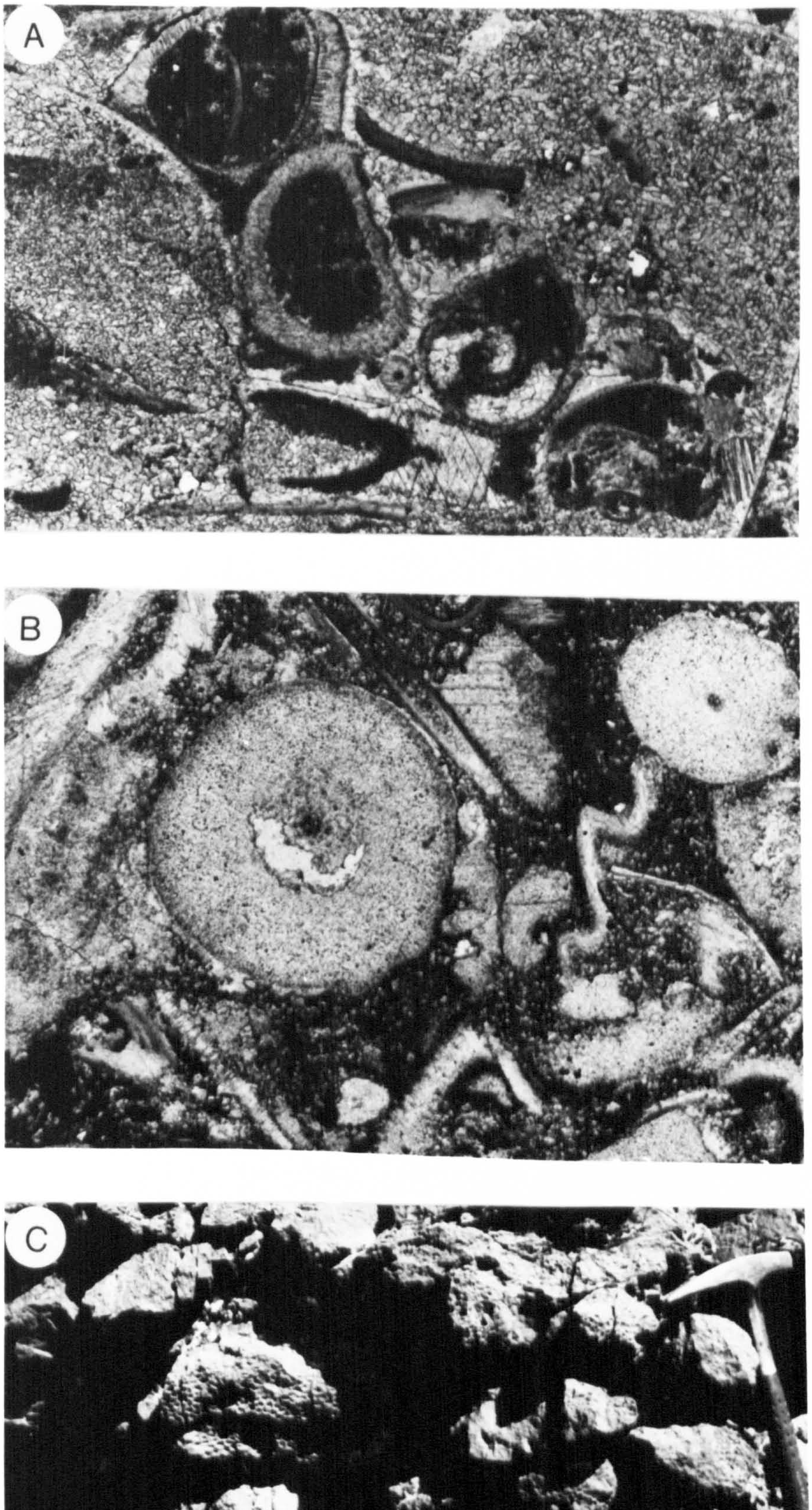
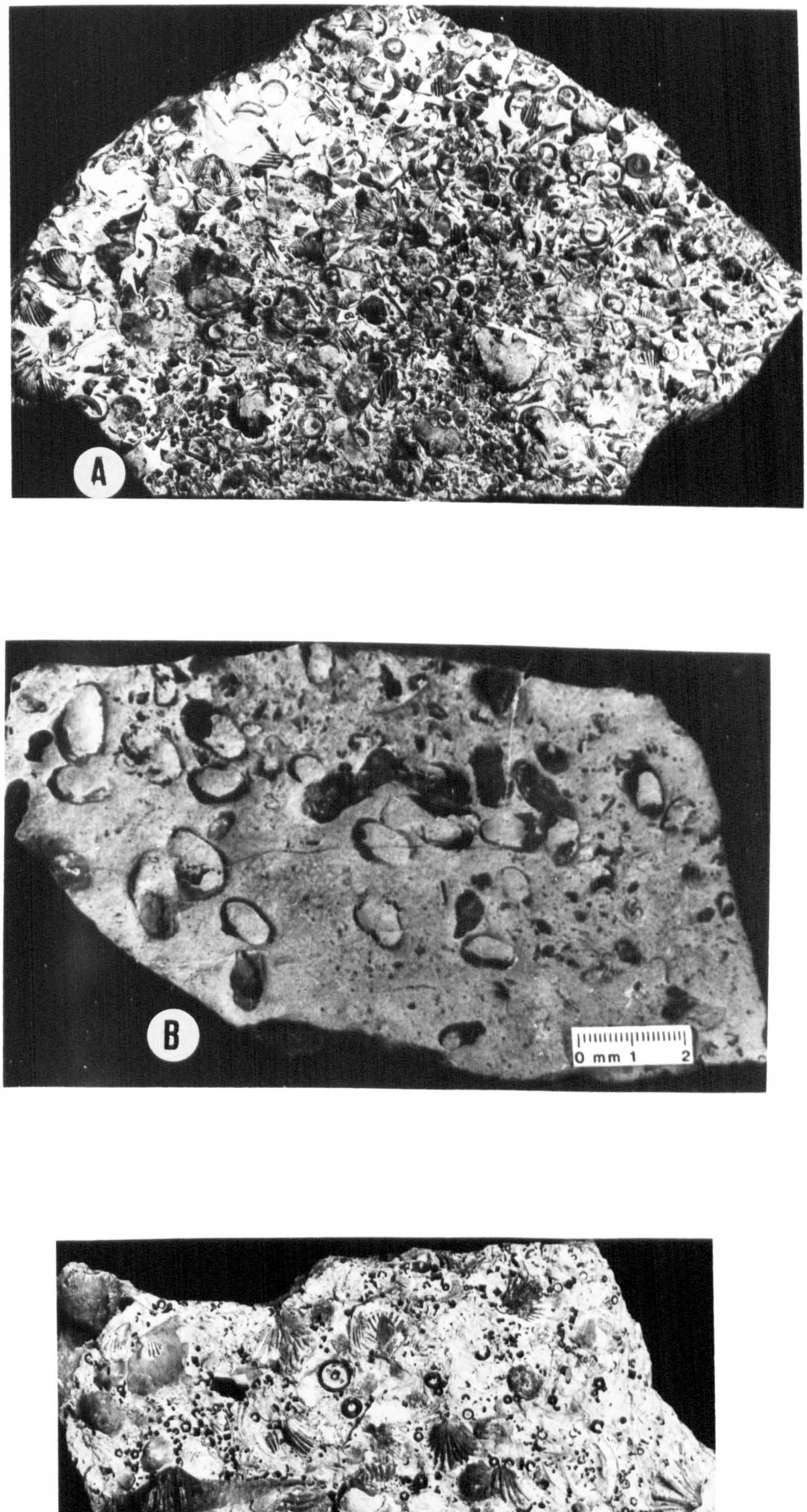

A
B
C

Plate 3.12

(a) Argillaceous limestone, with shell debris (coquina), mainly brachiopods and crinoids, $\times\frac{3}{4}$. Hutk section, level 195 m, sample Hb48.

(b) Argillaceous limestone, showing bivalve shells on the bedding surface.
Hutk section, level 17 m, sample HbI2.

(c) Argillaceous limestone, showing brachiopods, mainly rhynconelida (small) and spiricerida (lower left), and crinoid fragments, $\times\frac{3}{4}$.
Shams Abad section, level 234, sample Sh35.


A
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CHAPTER 4

BRACHIOPODS

4.1 INTRODUCTION

Brachiopods are the most common macrofossils in the Devonian formations of the Kerman area; for this reason they are potentially important tools for understanding biochronology, palaeoenvironment and also invertebrate evolution.

Over the past twenty years there has been a large increase in data published on brachiopod communities, especially those in the Devonian rocks of north and northeastern Iran (Gaetani, 1965; Sartenaer, 1966, 1968; Brice et al., 1973). However, palaeontological study of the Devonian rocks in Kerman has so far been neglected.

The Devonian strata are widely exposed over the northern part of Kerman (Fig. 3.1). Field work over a wide geographical region in Kerman shows that the brachiopods of this area are highly diverse.

The aim of the present study was to identify previously unidentified brachiopods. In so doing it provides information useful for the correlation of Devonian sediments within Iran. This basic taxonomic information is also necessary for further biostratigraphic, palaeoecologic analysis and correlation of the Devonian strata of southeast central Iran.

In this study 1831 individual brachiopods were obtained from the following five outcrops in northern Kerman:

a) Gerik section, 269 specimens including 12 taxa,

b) Hutk section, 1383 specimens including 24 taxa,

c) Nedenu section, 21 specimens including 3 taxa,

d) Shams Abad section, 134 specimens including 9 taxa,

e) Tizi section, 45 specimens including 5 taxa.

In addition, 180 rock samples, each containing about 10 fossils, were collected, most (110 samples) from the Hutk section (see Figure 3.1 for the location of the sections).

The fossils under examination were collected from the measured stratigraphic sections. Description of the lithological sequences is given in Chapter 3. The fossils, originally formed of calcium carbonate, occur mainly in the argillaceous limestone beds. At each locality as many brachiopods as possible were collected, special attention being paid to small specimens. In this way it was hoped to secure individuals at all stages of development.

The faunas indicate Frasnian and Famennian ages for the strata in the area of study.

4.2 PALAEONTOLOGY

Brachiopods in the Kerman district were first reported by Tipper (1921) who assigned a Carboniferous age to the rocks exposed northeast of Kerman town. The presence of these faunas was mentioned later by Clapp (1940), Hückreide et al. (1962), Durkoop et al. (1967) and Dimtrijevic (1973). Systematic description of 31 previously unpublished brachiopod taxa from the Kerman region includes members of the following orders:

1) Orthida, 54 specimens belonging to one taxon,
2) Rhynchonellida, 581 specimens belong to 5 taxa,
3) Spiriferida, 1165 specimens belong to 19 taxa,
4) Strophomenida, 46 specimens belong to 5 taxa,
5) Terebratulida, 5 specimens belong to one taxon.

The biostratigraphic sections are measured from the reference horizons as given below:

a) Gerik section, the lower limit of the outcrop (Fig. 3.2)
b) Hutk section, the top of the Red Sandstone facies (Fig. 3.3)
c) Nedenu section, the top of the first sandstone horizon overlying the Jurassic shales (Fig. 3.4)

d) Shams Abad section, the top of the conglomerate unit (Fig. 3.5)

e) Tizi section, the lower limit of the outcrop (Fig. 3.6).

In this investigation the systematic classification follows mainly that described in the *Treatise of Invertebrate Palaeontology*, Part M, vols. 1 and 2, "Brachiopoda" (Moore, 1965). In addition, Brice's (1971) classification was followed for the taxa not mentioned in the Treatise.

The faunas collected in this study are housed, for the most part, in the collection of the Department of Palaeontology of the Natural History Museum, London (BD.... samples). Some 950 samples are also housed in the Department of Geology, University of Shahid Bahonar, Kerman, Iran. (Abbreviations Nb, Gb, etc. indicate sections sampled.)

4.3 SYSTEMATIC PALAEONTOLOGY

4.3.1 **Order:**	Orthida	Schuchert and Cooper, 1932
Suborder:	Orthidina	Schuchert and Cooper, 1932
Superfamily:	Enteletacea	Waagen, 1881
Family:	Rhipidomellidae	Schuchert, 1913
Genus:	*Rhipidomella*	Oehlert, 1890
	Rhipidomella sp.	

(Plate 4.6, Figs. 7a-b)

Material: Fifty-four specimens; some are deformed due to compression and are partly broken.

Description: The shell is of medium sized *Rhipidomella*; it is circular to subcircular in outline. The size variation (Fig. 4.1) data points fall within an almost single zone on the graph, perhaps indicating a single community. The valves are very thin and the hinge line is short. The fold and sulcus are not well developed. The delthyrium is open but the notothyrium and chilidial plates are small. The diductor scars are well exposed with large medium septum. The costae are very fine but growth lamellae are well developed.

Occurrence: the genus *Rhipidomella* shows a wide range from Silurian to Lower Carboniferous in many areas (Moore, 1965). It was found with Famennian brachiopods, e.g. *Ptychomaletoechia elburzensis* in Kerman.

Localities: Gerik Section level 190-210 m, sample BD9029, Hutk section level 305 m, sample BD9030 and Shams Abad section, level 190-230 m, sample Sh140.

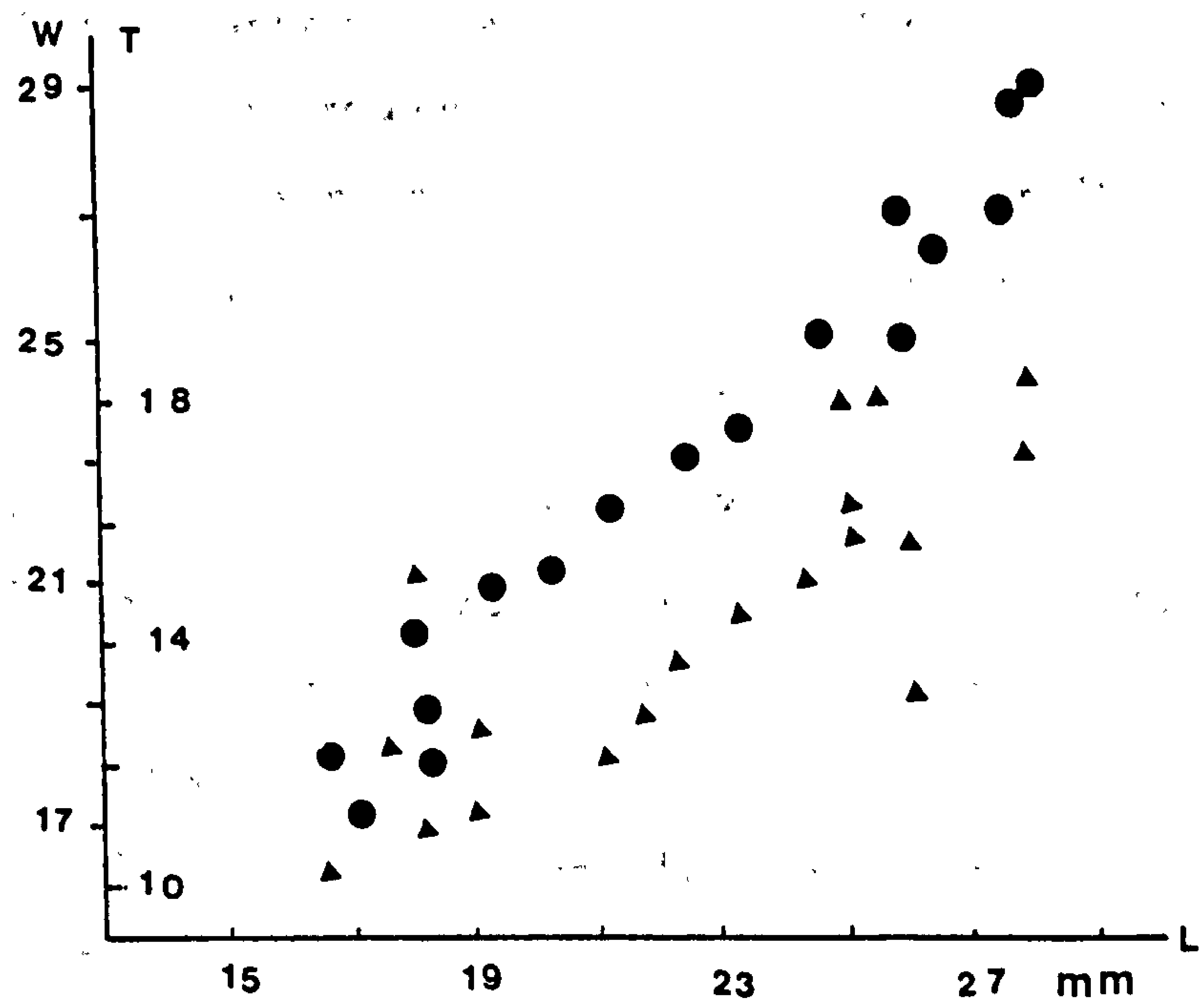

Fig. 4.1- Graphical comparison of the length/width (●) and length/thickness (▲)of 19 Rhipidomella sp.

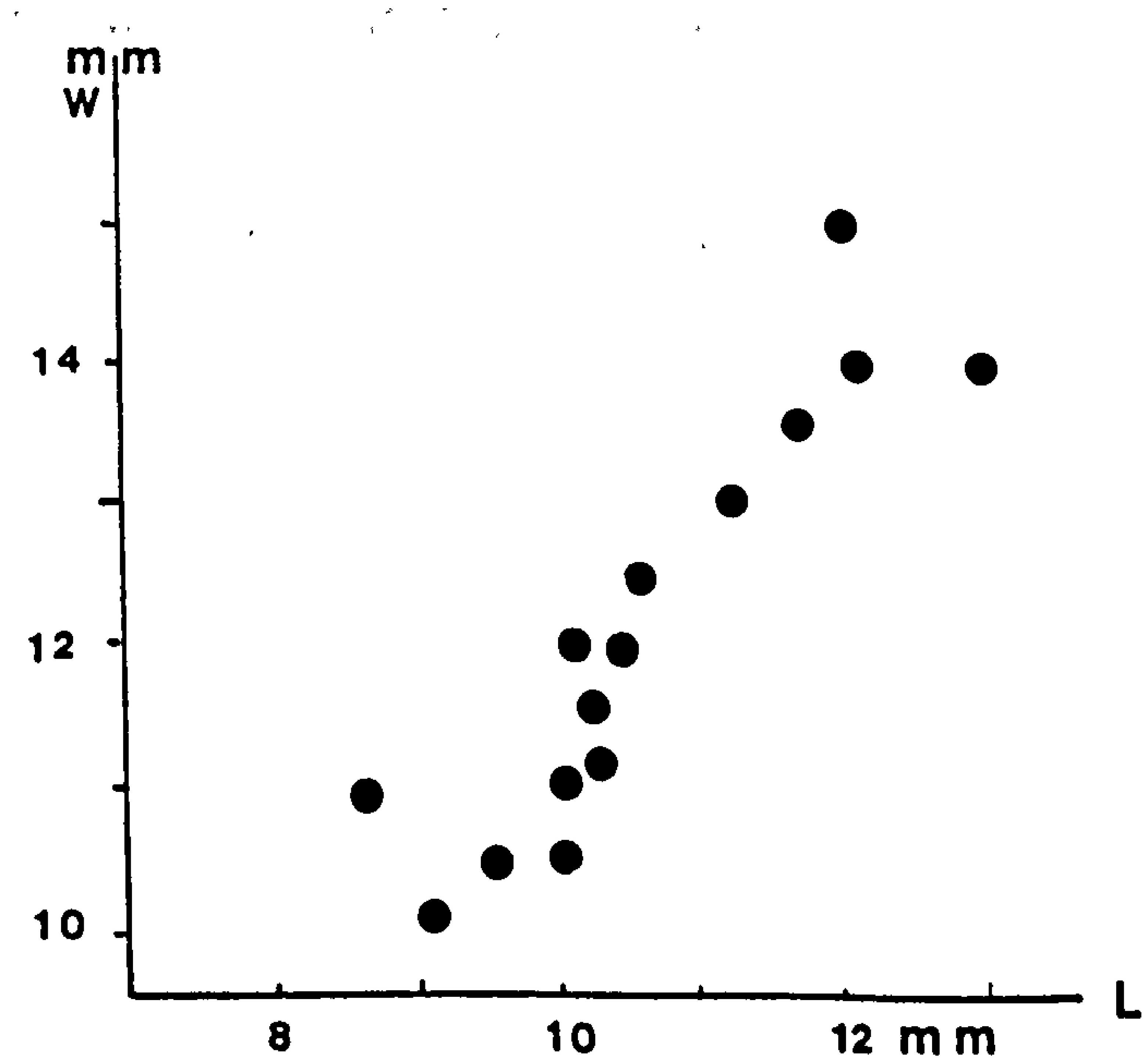

Fig. 4.2- Graphical comparison of length/width of 12 Ptychomaletoechia elburzensis.

4.3.2 Order:	Rhynchonellida	Kuhn, 1949
Superfamily:	Rhynchonellacea	Gray, 1848
Family:	Camarotoechiidae	Schuchert and Levene, 1929
Genus:	*Paurorhyncha*	Cooper, 1942
	Paurorhyncha bikniensis	Gaetani, 1965

(Plate 4.1, Figs. 2 and 3)

Material: Two specimens, both in reasonably good condition.

Description: The shell is large size for the genus and has inflated valves. It is subtriangular in outline with moderately deep and wide sulcus, originating from the beak.

The pedicle valve is convex posteriorly; it has a strong umbo projecting beyond the hinge line. The sulcus covers one half of the shell width.

The brachial valve is regularly convex posteriorly. The beak is curved and the fold is wide but low in relief.

The simple and well developed costae originate from the beak. The growth lines are present on both valves which are restricted near the anterior margin.

Occurrence: Lower Geirud Formation, N. Iran, Famennian (Gaetani, 1965).

Locality: Hutk section level 230 m, sample BD9031-9032.

Family: Rhynchonellidae Gray, 1848

Genus: *Cyphoterorhynchus* Sartenaer, 1964

Cyphoterorhynchus arpaensis (Abramian, 1957)

(Plate 4.1, Figs. 1a-e)

Material: Ninety-three specimens, mostly in good condition.

Description: The shell is of medium size for the genus, biconvex and triangular to subrounded in outline.

The pedicle valve has a projecting umbo, curved over the hinge line. The flanks are slightly convex. The sulcus originates at about 60% to 70% of the length from the beak; it is very wide, covering almost 80% of the pedicle surface. The hinge line is curved with a length of about one-half the shell width.

The brachial valve is convex and slightly curved posteriorly. The flanks are steep and slightly concave laterally. The fold has very low relief and originates from the beak.

The ribs are fine but growth lines are not preserved.

Occurrence: The genus *Cyphoterorhynchus* has a broad geographic distribution and is represented by several species and subspecies which have been found in northwest Pakistan, west Australia, Armenia and east Iran (Sartenaer, 1966). *Cyphoterorhynchus arpaensis* has been found in east Iran and Afghanistan, dated as Middle to Upper Frasnian (Brice, 1971).

Localities: Hutk section, level 40-70 m, sample BD9033 and Tizi section, level 145 m, sample BD9034.

Family: Trigonirhynchiidae McLaren, 1965

Genus: *Ptychomaletoechia* Sartenaer, 1961

Ptychomaletoechia deltidialis Gaetani, 1965

(Plate 4.1, Figs. 4a-e)

Material: Ten isolated specimens mostly in good condition.

Description: The shell is of medium size for the genus. It is biconvex and subpentagonal in outline.

The pedicle valve has a strong and suberect umbo but does not project beyond the hinge line. The valve is regularly convex in longitudinal section and the flanks are strongly inclined. The sulcus is wide and begins at about one-third of the length from the umbo.

The brachial valve has a slightly incurved umbo. It is more convex than the pedicle valve in longitudinal section. The fold has medium relief and originates at about one-quarter of the length of the brachial valve, measured from the umbo. The flanks are inclined near the commissure.

The costae are simple, large and originate from the umbo.

Occurrence: *Ptychomaletoechia deltidialis* was found in the Geirud Formation (Famennian in age), north Iran (Gaetani, 1965).

Locality: Hutk section, level 190 m and 250 m, sample BD9035-9036.

Genus: *Ptychomaletoechia* Sartenaer, 1961

Ptychomaletoechia elburzensis Gaetani, 1965

(Plate 4.1, Figs. 5a-e)

Material: 276 specimens, mostly in good condition but some are partially compressed.

Description: The shell is small for the genus and subellipsoidal in outline. Maximum width occurs at about two-thirds of the total length of the shell. The valve margins show a zig-zag commissure. The size variation (Fig. 4.2) data points fall within a well-defined single zone on the graph, perhaps indicating a single community.

The pedicle valve has a prominent umbo. The sulcus is deep and wide, with a width greater than the half-width of the shell. The sulcus originates at about 20% to 25% of the length from the umbo.

The brachial valve has a strong curved beak. The well defined fold originates at about 30% of the length from the beak.

The costae are prominent, with sharp crests; they originate at the beak. The costae are not differentiated within the fold nor sulcus.

Occurrence: *Ptychomaletoechia elburzensis* has been found in the Famennian formations in north Iran (Gaetani, 1965).

Localities: Hutk section, level 195-242 m, sample BD9037-9038, Shams Abad section, level 100-210 m, sample Sh14 and Sh16, Tizi section, level 195 m, sample Tb58 and Nedenu section, level 460 m, sample Nb21.

Genus: *Rhipidiorhynchus* Sartenaer, 1966

Rhipidiorhynchus kotalensis Brice, 1979

(Plate 4.1, Figs. 6a-e)

Material: 250 isolated specimens, all in good condition.

Description: The shell is subelliptical in outline, it is medium to large size for the genus and inflated in profile. The commissure is slightly crenulated by the high costae, and well developed posteriorly.

The pedicle valve has a projecting umbo. The flanks are convex near the sulcus and slope gently toward the lateral commissure. The sulcus is well developed; it originates at about 20% to 25% of the length from the beak. The delthyrium and dentidial plates are very small.

The brachial valve is strongly convex posteriorly. The flanks are steep and become concave anteriolaterally. The fold is high anteriorly; it originates a short distance from the beak.

The costae are well defined and unbranched.

Occurrence: *Rhipidiorhynchus kotalensis* has been reported from the Upper Frasnian and Famennian formations in Afghanistan and Iraq (Brice 1971). In Kerman it has been exposed only within the Famennian strata.

Locality: Hutk section, level 240 m, sample BD9039 and level 340 m, sample BD9040.

4.3.3 Order:	Spiriferida	Waagen, 1883
Suborder:	Athyrididina	Boucot et al., 1964
Superfamily:	Athyridacea	M'Coy, 1844
Family:	Athyrididae	M'Coy, 1844
Genus:	*Anathyris*	Von Peetz, 1901
	Anathyris sp.	

(Plate 4.1, Figs. 7a-e)

Material: Eight isolated specimens, three in good condition but others partially deformed or partly broken.

Description: The shell is small for the genus and subrounded to triangular in outline. The valves are moderately biconvex, with approximately equal convexity posteriorly.

The pedicle valve has wide beak and is slightly curved. The foramen has not been observed. The sulcus is wide and low in relief.

The brachial valve has a small curved umbo. The fold originates near the beak. The interarea and dental plates are not well defined.

Microornament consists of numerous fine growth lines which are commonly accentuated anteriorly.

Occurrence: *Anathyris* has been reported from the Jauf Formation, Saudi Arabia, Late Early Devonian (Boucot, 1984). The genus also occurs in the Upper Devonian (Frasnian) of Eurasia.

Locality: Gerik section, level 60 m, sample BD9041.

Genus: *Athyris* M'Coy, 1844

Athyris chitralensis Reed, 1922

(Plate 4.2, Figs. 1a-e)

Material: Forty isolated specimens in good condition, mostly complete.

Description: The shell is large size for the genus, biconvex, inflated and suboval in outline, with thick valves. Maximum thickness of the shell is at about midway of the length.

The pedicle valve shows a well developed umbo and large foramen; a shallow and wide sulcus begins at about halfway from the beak.

The brachial valve has a curved umbo and a distinct fold low in relief which originates near the umbo. The commissure is curved at flanks.

Occurrence: *Athyris chitralensis* was dated by Reed (1922) in Koragh, Pakistan, and by Gaetani (1965) in the Geirud section, north Iran, as Frasnian. On the basis of other fossils in the study area the Frasnian age has been confirmed.

Location: Hutk section, level 160-170 m, sample BD9042-9043.

Genus: *Cleiothyridina* Buckman, 1906

Cleiothyridina coloradensis (Girty, 1900)

(Plate 4.4, Figs. 4a-e)

Material: Forty-nine specimens, mostly in good condition.

Description: The shell is small for the genus, has biconvex valves, and is subtriangular to subrounded in outline. The hinge line is shorter than the maximum width of the shell.

The pedicle valve has a robust umbo and curved over the hinge line. The deltidium and interarea are not well developed. The sulcus is weak, originating about midlength from the beak.

The brachial valve is convex posteriorly with more convexity than the pedicle valve. The umbo is developed beyond the hinge line. A low relief fold is clearly defined, originating from the beak.

Ornament is formed of well preserved ribs. The growth lines are well defined.

Occurrence: *Cleiothyridina coloradensis* was reported from the Famennian formations in west Afghanistan (Brice, 1971) and in north Iran (Gaetani, 1965). In Kerman it has been found within Frasnian and Famennian trata.

Location: Gerik section, level 65 m, sample BD9044, and level 175 m, sample BD9045; Shams Abad section, level 185 m, sample BD9046.

Cleiothyridina reticulata Stainbrook, 1947

(Plate 4.2, Figs. 6 and 7)

Material: Five incomplete specimens; brachial valves only.

Description: The brachial valve is convex, subcircular in outline tending to be more spread laterally with projecting beak, and a poorly developed fold which originates from the beak. There are well marked growth lines with lamella over the whole surface; lamellae expand anteriorly as long flat spines.

Occurrence: *Cleiothyridina reticulata* has been previously reported in Khoshyielagh, north Iran, and in southwest Afghanistan as part of an Upper Famennian fauna. Its occurrence in the Hutk section can thus be taken to indicate Famennian age.

Location: Hutk section, level 195 m, sample MDH157, and level 242 m, sample MDH160.

Genus: *Composita* Brown, 1849

Composita sp.

(Plate 4.2, Figs. 2a-e)

Material: 272 isolated specimens, mostly in good condition.

Description: The shell is circular to subpentagonal in outline. It is moderately inflated, and of biconvex profile. The size variation (Fig. 4.3) data points fall within a well defined single zone on the graph, perhaps indicating a single community.

The pedicle valve shows maximum curvature posteriorly; a well developed projecting umbo and rounded foramen at its beak are present. The shallow and wide sulcus originates at about midlength. A conspicuous commissure and short dental plates are present.

The brachial valve is more convex posteriorly. The fold is indistinct laterally. The muscle scars are narrow and elongated, but other internal structures were not observed.

The external surface is smooth, lacking ribbing, but with growth lines commonly accentuated anteriorly.

Occurrence: The genus *Composita* was reported from the Upper Devonian to Carboniferous strata in the Geirud Formation (Gaetani, 1965). Its occurrence in Kerman is with other brachiopods, e.g. *Cleiothyridina*, regarded as Famennian.

Location: Hutk section, level 195-358 m, sample BD9047, and Shams Abad section, level 185-240 m, sample BD9048.

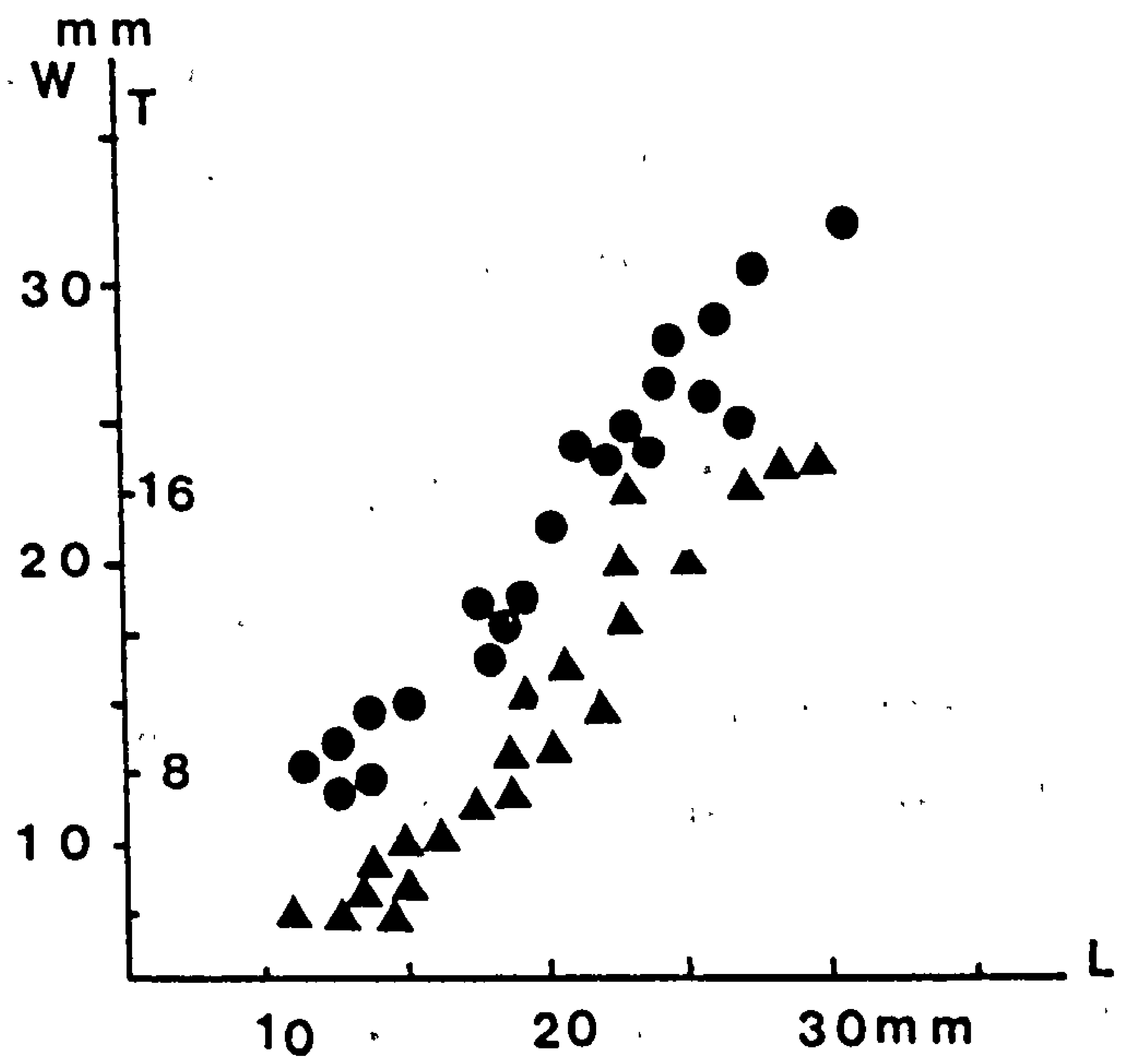

Fig. 4.3- Graphical comparison of the length/width (●) and length /thickness (▲) of 22 Composita sp.

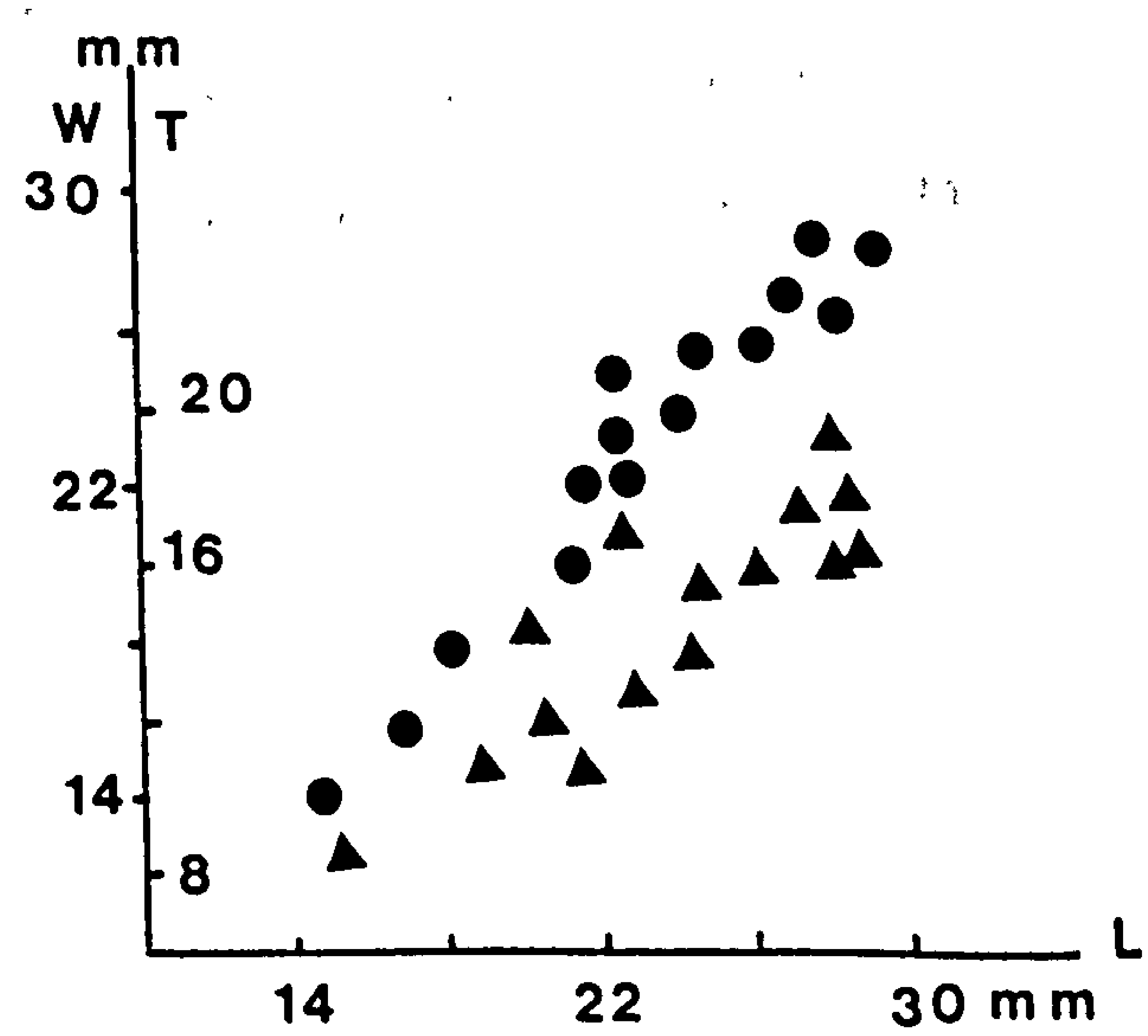

Fig. 4.4- Graphical comparison of the length/width (●) and length/thickness (▲) of 15 Spinatrypina robusta.

Suborder:	Atrypidina	Moore, 1952
Superfamily:	Atrypacea	Gill, 1871
Family:	Atrypidae	Gill, 1871
Subfamily:	Atrypinae	Gill, 1871
Genus:	*Anatrypa*	Nalivkin, 1941
	Anatrypa sp.	

(Plate 4.4, Figs. 1a-e)

Material: Seven specimens, partly decorticated.

Description: The shell is medium to large size for the genus; it is convexi-plane in outline. The fold and sulcus are absent or indistinct. The commissure is sharp.

The pedicle valve is highly convex posteriorly and the beak has slight curvature. The hinge line is subcircular and shorter than the maximum width. The deltidium and interarea are absent.

The brachial valve is slightly sulcate to nearly flat.

Costae are present but the growth lines are absent.

Occurrence: The genus *Anatrypa* has been reported from the Middle and Upper Devonian (Frasnian) formations in Europe (Moore, 1965, p. H639), Its occurrence with the other brachiopods, e.g. *Uchtospirifer multiplicatus* in this horizon in Gerik section indicates a Frasnian age.

Locality: Gerik section, level 69 m, sample BD9049.

Genus: *Spinatrypina* Rzhonsnitskaya, 1964

Spinatrypina chitralensis (Reed, 1922)

(Plate 4.2, Figs. 3a-e)

Material: Seventy-five specimens, mostly in good condition.

Description: The shell is small and subcircular in outline. It is biconvex with pedicle valve slightly more convex. The valves are equal in dimensions. The beak is somewhat incurved.

The pedicle valve carries a distinct umbo with a little curvature. The sulcus is not well defined.

The brachial valve has a small umbo, and the fold is not distinguishable. The dental plates are not distinct; costae are clearly observable. Growth lines are stepped and carry fine striations parallel to the edge but without spines or ornament.

As far as can be determined, specimens are very similar to those described by Brice (1971).

Occurrence; *Spinatrypina chitralensis* has been reported in eastern Iran (Gaetani, 1967) and in Afghanistan (Brice, 1971) as a Frasnian species.

Locality: Hutk section, level 24-34 m, sample BD9050 and Tizi section, level 130 m, sample BD9051.

Spinatrypina robusta Copper, 1967

(Plate 4.4, Figs. 3a-e)

Material: Forty-seven specimens were collected, mostly in good condition.

Description: The shell is small size for the genus and subcircular in outline. It is unequally biconvex with the brachial valve more convex than the pedicle valve. The sulcus and the fold have a very weak appearance. The size variation (Fig. 4.4) data points fall withing a well defined single zone on the graph, perhaps indicating a single community.

The anterior commissure is slightly deflected toward the brachial valve; the ventral beak is well projecting but does not cross the hinge line. The deltidium and interarea have not been seen. The ribs are well developed but the growth lines are not well preserved.

Occurrence: *Spinatrypina robusta* has been reported from the Frasnian formations in Afghanistan (Brice, 1971) and in the northeastern USSR (Nikolaev and Rzhonsnitskaya, 1967).

Locality: Gerik section, level 62 m, sample BD9052, and level 70 m, sample BD9053.

Suborder:	Spiriferidina	Waagen, 1883
Superfamily:	Spiriferacea	King, 1846
Family:	Cyrtospiriferidae	Termier and Termier, 1949
Genus:	*Cyrtospirifer*	Nalivkin, 1919 (1924)
	Cyrtospirifer asiaticus	Brice, 1971

(Plate 4.5, Figs. 1a-d)

Material: Fourteen specimens, some are decorticated and some are slightly deformed.

Description: The shell is moderately inflated but with a high triangular posterior profile; it is subtrapozoidal in outline and commonly has small wings.

The pedicle valve has a projecting umbo which is slightly curved. The interarea is weakly concave, triangular in shape and covers almost the full width of the shell. The deltidial plates are not preserved. The sulcus is relatively deep.

The brachial valve has low convexity and the umbo projects slightly beyond the hinge line.

The costae are fine and simple. The growth lines are well defined near the anterior margin.

Occurrence: *Cyrtospirifer asiaticus* has been reported from the Famennian formations in Afghanistan (Brice, 1971).

Locality: Gerik section, level 160-165 m, sample BD9054.

Genus: *Cyrtospirifer schelonicus* Nalivkin, 1941

(Plate 4.3, Figs. 1a-e)

Material: Twenty-seven specimens of *Cyrtospirifer schelonicus*, some in good condition but partly decorticated.

Description: The shell appears subtrapezoidal to oval in outline with extending wings. It is strongly inflated. The hinge line is equal to the maximum width of the shell. The cardinal angle is about 25° to 30°. The size variation (Fig. 4.5) data points fall within a well-defined single zone on the graph, perhaps indicating a single community.

The pedicle valve is convex with a well developed umbo not projecting far over the area. The dental plates are extended and the delthyrium is broad. A strong sulcus originates from the umbo and flanks are extended.

The brachial valve is convex with a fold of high relief. The umbo is small, with developed dental plates. The flanks of the valves are well spread.

Simple costae are clearly seen. The growth lines are well developed near the anterior margin of the shell.

Occurrence: *Cyrtospirifer schelonicus* has been assigned to the Frasnian formations of central and western Afghanistan (Brice, 1971).

Localities: Hutk section, level 160-178 m, sample BD9055, and Shams Abad section, level 160 m, sample BD9056.

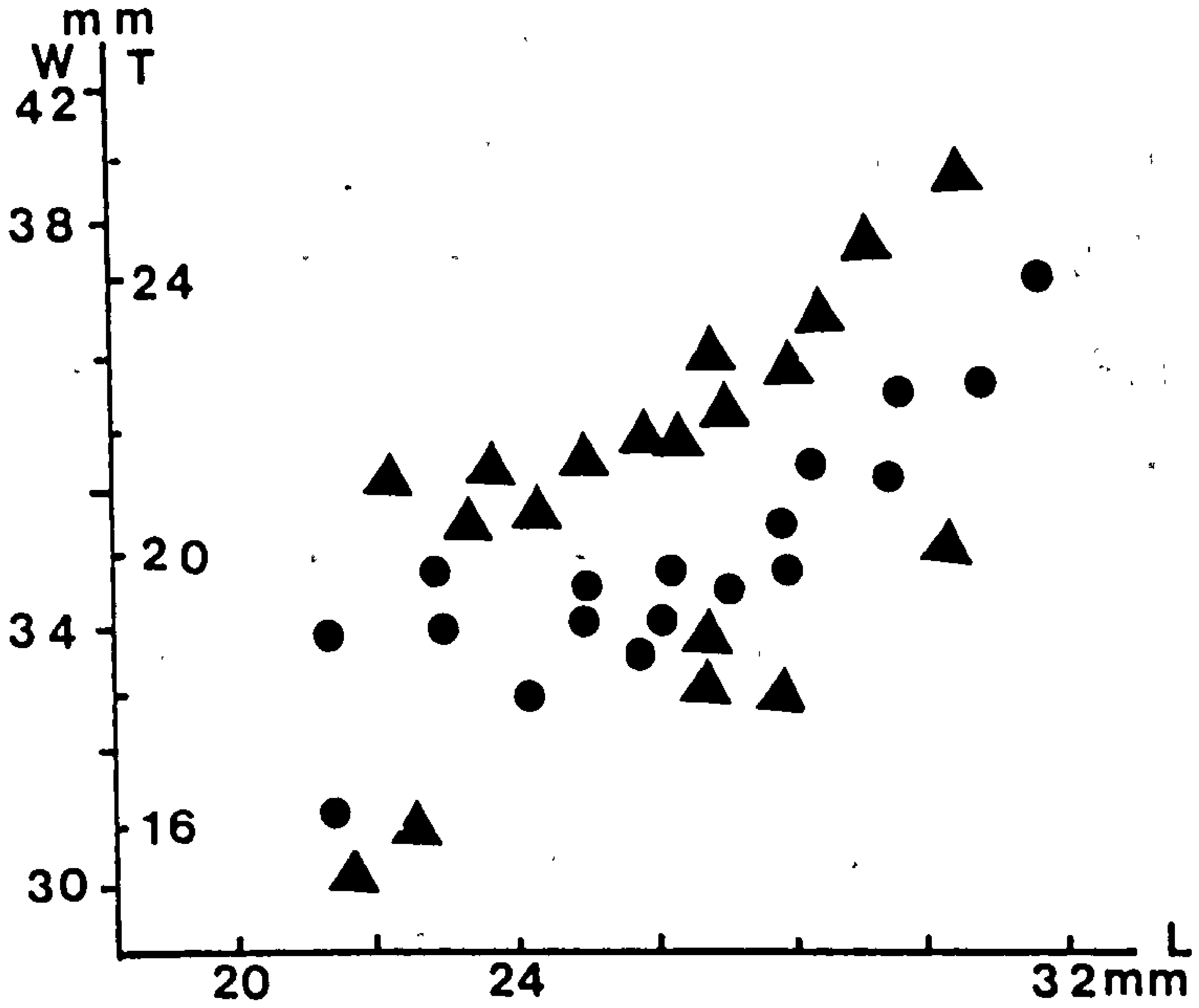

Fig. 4.5 Graphical comparison of the length/width (●) and length/thickness (▲) of 19 Cyrtospirifer schelonicus.

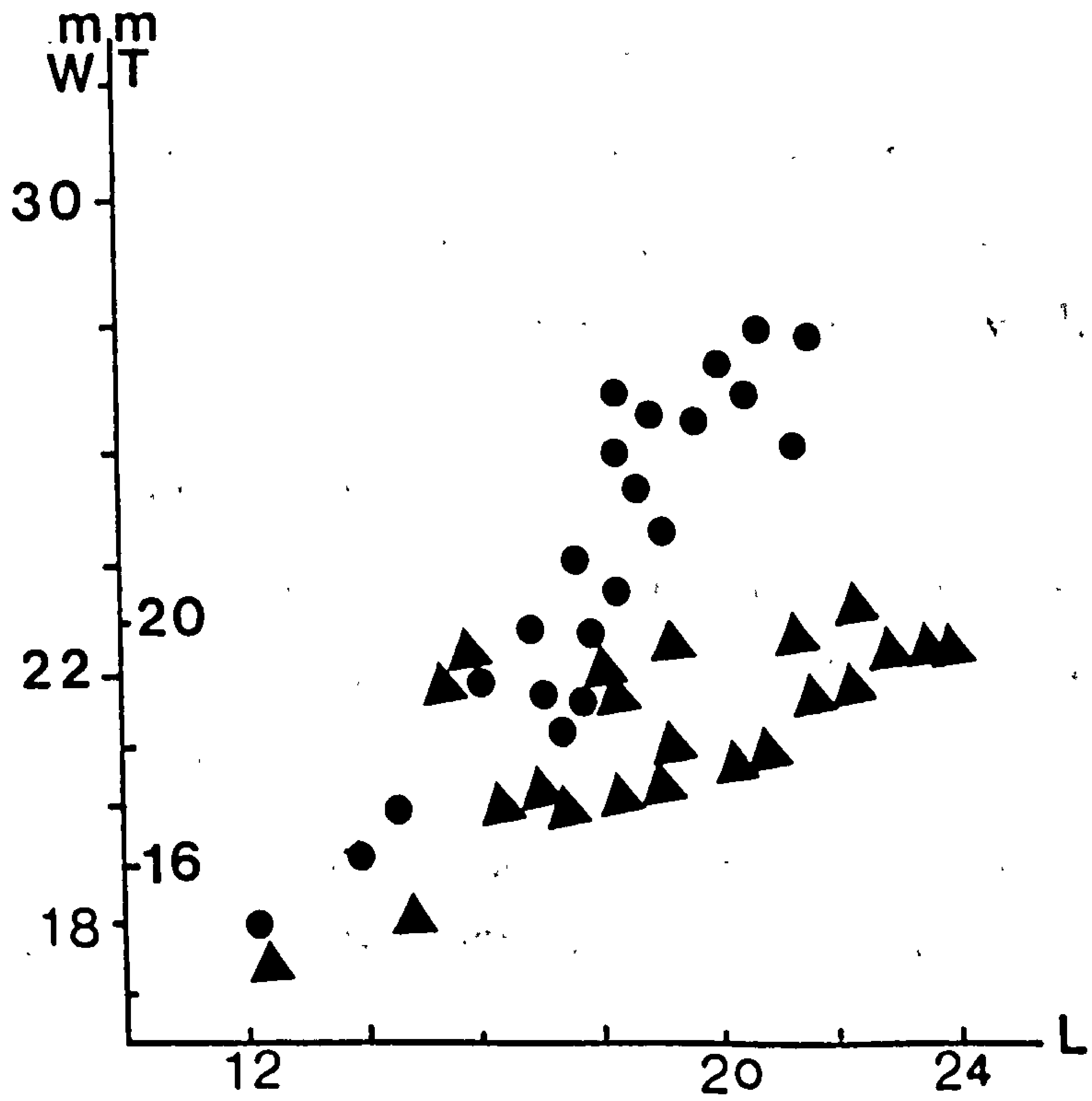

Fig. 4.6- Graphical comparison of the length/width (●) and length/thickness (▲) of 22 Cyrtospirifer verneuili.

Cyrtospirifer supradisjunctus (Obrutschew, 1913)

(Plate 4.2, Figs. 4a-e)

Material: Thirty-two specimens have been collected. Some are in good condition, others are partly decorticated or moderately deformed.

Description: This is a medium size member of the Spiriferida, semi-circular in outline, having small winged flanks; it is biconvex with maximum thickness about midlength; the cardinal angle varies from 15° to 20°; the line of commissure is well defined and curved.

The pedicle valve is semi-circular in outline and its maximum convexity appears near the umbonal region. The umbo is curved but does not cross the hinge. A small interarea and short dental plates are present. The sulcus is narrow, originating from the umbo.

The brachial valve shows less convexity than the pedicle valve; it is semi-circular in outline with a very small bent umbo. The fold has low relief. The interarea and deltidium are well developed.

The costae have simple and medium to fine appearance. The growth lines are well defined near the exterior margin with stronger appearance at the pedicle valve than the brachial valve.

Discussion: In general shape and contour the specimens under consideration seem to possess some similarity to *Cyrtospirifer supradisjunctus* as considered by Vandercammen (1959), but with some minor differences. However, the specimens do not fit any other species the author has been able to compare.

Occurrence: *Cyrtospirifer supradisjunctus* has been found in Belgium accompanying other *Cyrtospirifer* species. A Frasnian age has been assigned to the species.

Localities: Hutk section, level 16-26 m, sample BD9057, Shams Abad section, level 94 m, sample BD9058, and Gerik section, level 60 m, sample Gb295.

Cyrtospirifer (Cy.) syringothyriformis Paeckelmann, 1942

(Plate 4.5, Figs. 2a-d)

Material: Eleven specimens; almost in good condition.

Description: The shell is medium size for the genus and subelliptical in outline, with slightly inflated valves. The hinge line region is extended as lateral wings.

The pedicle valve has slightly curved umbo. The sulcus is evenly concave, medium to narrow, moderately deep and in transverse section is regularly arched. The flanks are widespread, ending with narrow and long wings. A broad interarea and a well developed deltidium are present.

The brachial valve has poorly developed and slightly curved umbo. The fold is narrow and low in relief. The valve is convex posteriorly with well extended flanks.

The costae are simple with medium to narrow interwalls between. They are slightly finer on the sulcus and fold then those on the flanks. The growth lines are clearly visible on the surface of the valves.

Occurrence: *Cyrtospirifer (Cy.) syringothyriformis* has been reported from the Middle to Upper Frasnian formations in western Europe and in the Geirud Formation (Famennian), north Iran (Gaetani, 1965). In Kerman it was found in Famennian formations.

Locality: Gerik section, level 160-176 m, sample BD9059.

Cyrtospirifer (Cyrtospirifer) verneuili (Murchison, 1840)

(Plate 4.2, Figs. 5a-e)

Material: 450 specimens were collected, mostly in good condition.

The shell is medium to small size for the species, semi-elliptical in outline and often winged. The hinge line is equal to the maximum width of the shell which appears slightly inflated. The size variation (Fig. 4.6) data points fall within a well-defined single zone on the graph, perhaps indicating a single community.

The pedicle valve has a curved umbo, with flanks spread, ending with small wings. The hinge area and delthyrium are prominent. The cardinal angle is about 30° to 35°. The sulcus is well developed.

The brachial valve has a small curved umbo, developed fold, low relief on the flanks and regular arched section. The flanks are long, ending with very small wings and small development area.

Simple costae are present on the surface of the semi-circular section. The intercostal spaces are about one-third of the width of the costae. The costae are finer within the fold and sulcus.

Discussion: Most of the specimens show much similarity to but smaller size than both the Belgian (Vandercammen, 1959) and the species from north Iran (Gaetani, 1965). On the other hand, they are very close in size to the specimens from southwest Afghanistan (Brice, 1971).

Occurrence: *Cyrtospirifer (Cy.) verneuili* is probably the most widely distributed Upper Devonian species throughout the world. It has been reported in the Frasnian-Famennian and the Lower Carboniferous. In the Franco-Belgian basin (its type area) it is abundant in the Upper Frasnian and the basal Famennian but is not found higher (Sartenaer, 1966). However, Gaetani (1965) pointed out that its distribution is much less wide than has been reported. In the central Alborz he found *Cyrtospirifer (Cy.) verneuili* in the Lower Famennian only, not higher there. According to Brice (1971), this species is of Frasnian age in southwest Afghanistan. With regard to the northeast Kerman area, a Frasnian to Lower Famennian age was assigned for the occurrence of the species.

Localities: Hutk section, level 16 m, sample BD9060, level 195 m, sample MDH1170; Gerik section, level 50-140 m, sample Gb20; Shams Abad section, level 10-170 m, sample BD9061; Tizi section, level 130-190 m, sample Tb25; and Nedenu section, level 325 m, sample Nb15.

Family:	Spiriferidae	Termier and Termier, 1949
Genus:	*Dichospirifer*	Brice, 1979
	Dichospirifer thylakistoides	(Brice, 1971)

(Plate 4.4, Figs. 1a-e)

Material: Twenty-seven specimens, mostly in good condition but partly compressed.

Description: The shell is medium size for the genus, biconvex and subcircular in outline with wings at the flanks. The hinge line is approximately equal to the maximum width.

The pedicle valve has a curved umbo crossing the hinge line. The delthyrium is small and interarea is narrow. The sulcus has low concavity originating from the umbo.

The brachial valve has a well developed fold originating from the umbo. The umbo is small and curved toward the internal pedicle valve. The diductor muscle scars are relatively strong. Both inter and outer hinge plates are present.

The ribs are medium to fine and numerous. The growth lines are strong and numerous near the anterior margin.

Occurrence: *Dichospirifer thylakistoides* has been reported from the Famennian in western Afghanistan (Brice, 1971) and the Khoshyielagh Formation, north Iran (Gaetani, 1967).

Locality: Hutk section, level 200-240 m, sample BD9062.

Genus: *Dmitria* Sidyachenko, 1961

Dmitria sp.

(Plate 4.3, Figs. 4a-e)

Material: Three isolated specimens partly decorticated.

Description: The shell is subcircular to suboval in outline; it is of medium size for the genus and moderately inflated. It has approximately equal length and width and the hinge line is much shorter than the maximum width.

The pedicle valve has a projecting umbo. The sulcus originates near the umbo and the commissure is well distinct.

The brachial valve is more convex than the pedicle valve and the fold is weak. The ribs are fine but growth lines are not preserved.

Occurrence: The genus *Dmitria* is known in the Upper Devonian formations in the USSR (Nikolaev and Rzhonsnitskaya, 1967).

Locality: Hutk section, level 210-230 m, sample MDH1274.

Genus: *Eobrachythyris* Brice, 1970

Eobrachythyris struniatus alatus (Gosselet, 1879)

(Plate 4.3, Figs. 2a-e)

Material: Forty-five specimens have been collected; some have broken flanks and posterior margin.

Description: The shell is medium to large size for the genus, semicircular in outline and strongly winged. It is biconvex and slightly inflated at the center but flattening toward the flanks. The shell is thick in the umbonal area. The size variation (Fig. 4.7) data points fall within a well-defined single zone on the graph, perhaps indicating a single community.

The pedicle valve has slightly curved umbo but not projecting much on the area. The sulcus is very weak but the flanks are well spread and end with narrow long wings. The interarea is long with medium to small deltidium.

The brachial valve has a moderately curved umbo not projecting beyond the hingeline. The fold is narrow. The flanks are well spread, terminating in narrow long wings.

The ribs are well developed and bifurcate at midway anteriorly. The spaces between the ribs on the sulcus are slightly smaller than those on the flanks. The growth lines are well defined near the anterior margin.

Occurrence: *Eobrachythyris struniatus alatus* has been reported from Famennian formations in Afghanistan (Brice, 1971).

Localities: Hutk section, level 195 m, sample BD9063; level 362 m, sample BD9064; and Shams Abad section, level 185 m, sample Sh120.

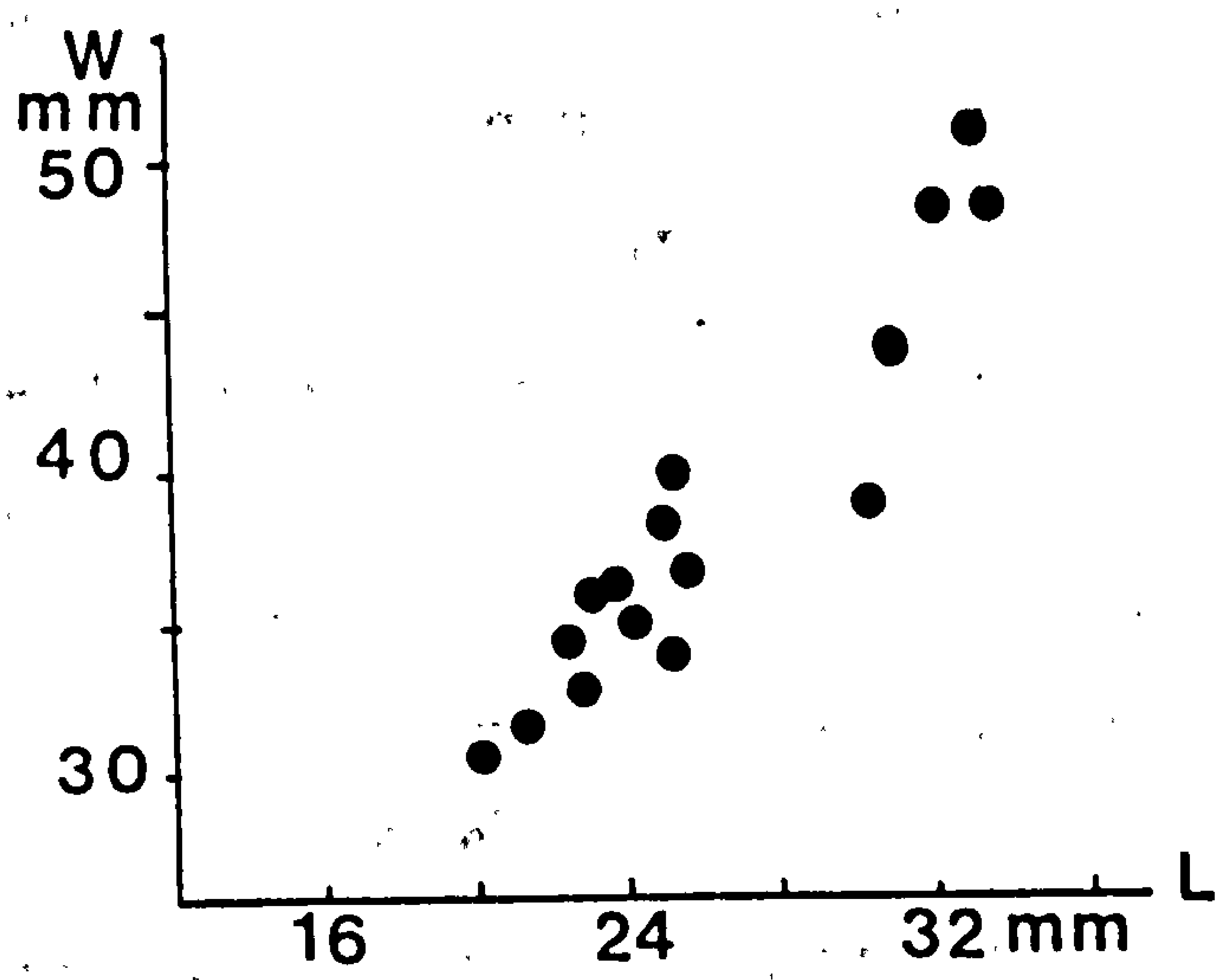

Fig. 4.7- Graphical comparison of the length/width of 15 Eobrachythyris struniatus alatus.

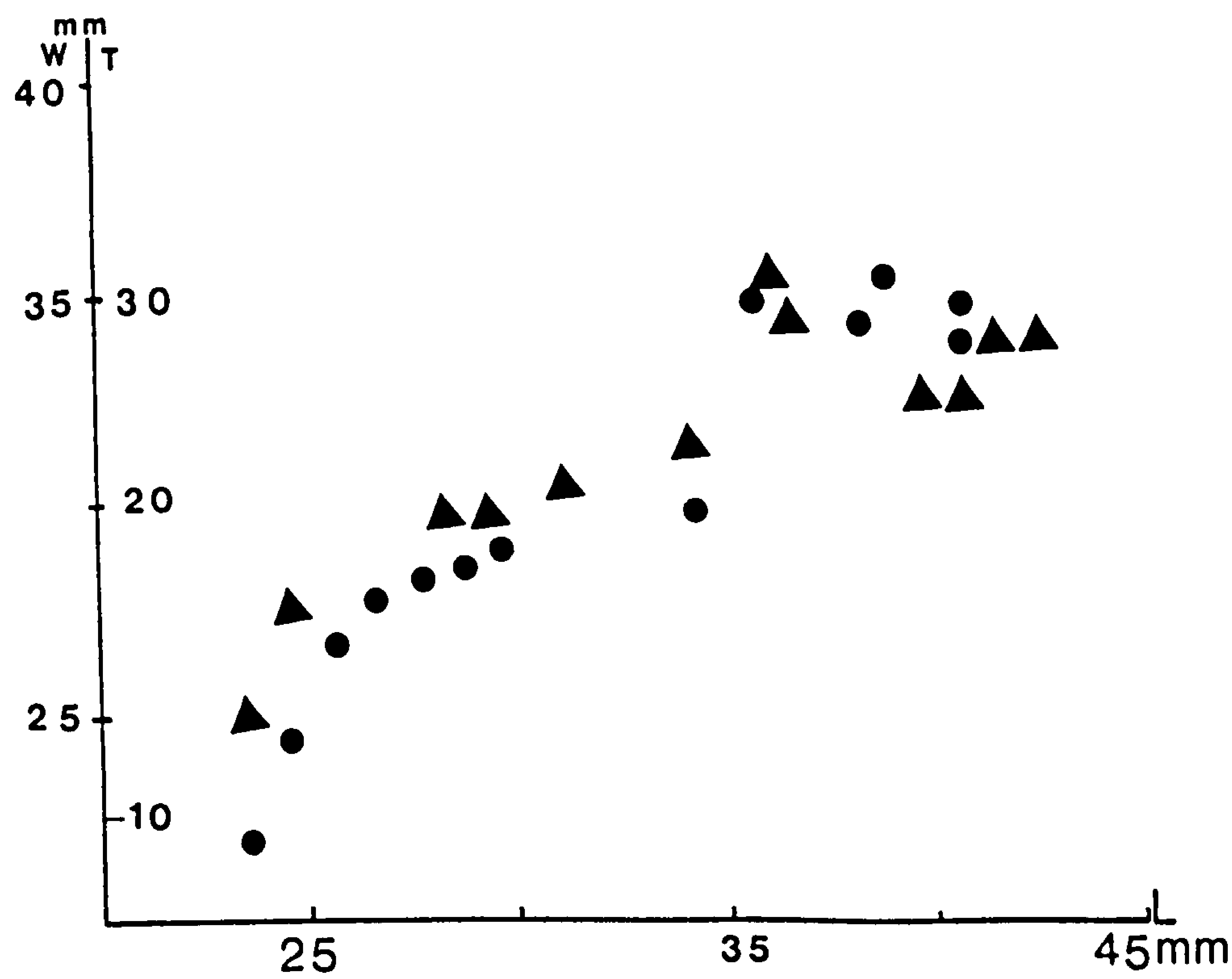

Fig.4.8- Graphical comparison of the length/width (●) and length/thickness (▲) of 13 Uchtospirifer multiplicatus.

Genus: *Sphenospira* Cooper, 1954

Sphenospira sp.

(Plate 4.3, Figs. 3a-b)

Material: Seven incomplete specimens, with only the posterior part of the pedicle valve.

Description: The shell is thick with a strong sulcus originating from the umbo. The deltidium and interarea are well developed. The ribs are present but low in relief.

Occurrence: *Sphenospira* occurs in the Upper Devonian in eastern North America (Moore, 1965). Here in Kerman it is found in the Famennian formations.

Locality: Hutk section, level 195-217 m, sample BD9065.

Genus: *Uchtospirifer* Lyashenko, 1957

Uchtospirifer multiplicatus Brice, 1971

(Plate 4.5, Figs. 3a-f)

Material: Forty specimens, mostly in good condition.

Description: The shell is large for the genus, triangular in outline and strongly biconvex in profile. It has small wings at the cardinal extremities. The hinge line is narrower than the maximum width. The fold and sulcus are well defined. The deltidium is moderately convex. The cardinal angle is about 25° to 30°. The size variation (Fig. 4.8) data fall within an almost single zone on the graph, possibly indicating a single community.

The pedicle valve is much longer than the brachial valve. It is strongly convex and curved toward the flanks. The umbo is highly curved but does not cross the hinge line. The interarea is well developed. The sulcus is deep and evenly concave; it originates from the umbo and contains about 15 ribs in average. The ribs within the sulcus are generally finer than those on the lateral flanks.

The brachial valve is strongly convex in anterior profile. The umbo is highly curved and a well-defined fold originates from the umbo.

The costae are simple and strong. The growth lines are weak, especially near the anterior margin.

Occurrence: *Uchtospirifer multiplicatus* is known in the Frasnian of Afghanistan and north Iran (Brice, 1971; Brice et al., 1973).

Locality: Gerik section, level 10 m, sample BD9066, and level 20 m, sample BD9067.

Superfamily:	Reticulariacea	Waagen, 1883
Family:	Elythidae	Frederiks, 1919 (1924)
Genus:	*Torynifer*	Hall and Clarke, 1894
	Torynifer sp.	

(Plate 4.2, Fig. 8; Plate 4.3, Fig. 8)

Material: Four pedicle valves in moderately good condition.

Description: The valves are medium size for the genus, convex and subcircular in outline. The umbo is large and bent over the hinge line. The sulcus originates from the umbo.

Microornament consist of conspicuous concentric growth lines and uniramous spines.

Occurrence: The genus *Torynifer* is held to be Upper Devonian to Mississippian in age (Moore, 1965) in the USA. *Toryniferella echinulata* also was reported from Famennian formations in southwest Afghanistan (Brice, 1971). In this area the genus is restricted to the zone of *Ptychomaletoechia elburzensis* and was regarded as Famennian in age.

Locality: Hutk section, level 195 m, sample MDH1342, and level 230 m, sample BD9068.

Family: Mucrospiriferidae Pitrat, 1965

Genus: *Tylothyris* North, 1920

Tylothyris subvaricosa (Hall and Whitfield, 1872)

(Plate 4.5, Figs. 4a-d)

Material: Eight specimens in relatively good condition; a few are slightly deformed by compression.

Description: The shell is small to medium size *Tylothyris*, biconvex posteriorly and subtrapozoidal in outline. The valves are uniplicate and the anterior commissure is w-shaped.

The pedicle valve is moderately convex in lateral profile, where convexity decreases anteriorly. The sulcus is v-shaped in cross section. It has generally seven to eleven ribs on the lateral slope. The interarea is wide and moderately convex near the beak. The delthyrium is open, rather wide, and is bounded by a marginal groove on the sides.

The brachial valve is moderately convex in lateral profile with convexity decreasing anteriorly. The fold has low relief. The beak is moderately incurved.

The costae are well exposed with high crests.

Microornament consists of prominent closely spaced concentric growth lines.

Occurrence: *Tylothyris subvaricosa* was reported from Frasnian and Famennian formations in New York, the Appalachians, Arizona and Montana (Rogers and Pitrat, 1987, p. 502). It is found with Frasnian spirifers, e.g. *Spinatrypina robusta* in the Gerik and Hutk sections.

Locality: Gerik section, level 70 m, sample Gb55, and Hutk section level, 25 m, sample BD9069.

4.3.4 **Order:**	Strophomenida	Öpik, 1934
Suborder:	Strophomenidina	Öpik, 1934
Superfamily:	Strophomenacea	King, 1846
Family:	Leptaenidae	Hall and Clarke, 1894
Genus:	*Leptaena*	Dalman, 1828
	Leptaena sp.	

(Plate 4.6, Figs. 1a-b)

Material: Two incomplete specimens, one external brachial valve and one internal pedicle valve.

Description: The shell is subcircular in outline and medium size for the genus. The ventral adductor muscle scars are long and with spreading diductor muscle scars. The posterior margin has a pronounced cardinal process.

The costae are well developed posteriolaterally.

Occurrence: The genus *Leptaena* has been reported from the Middle Ordovician to Devonian (Frasnian) in Sweden and England (Moore, 1965, p. 391). It was found in Upper Devonian formations in northeast and central Iran (Zamedi, 1976) and has been found together with Famennian brachiopods, e.g. *Rhipidiorhynchus kotalensis* in Kerman.

Locality: Hutk section, level 340 m, sample BD9069.

Suborder:	Chonetidina	Muir-Wood, 1955
Family:	Chonetidae	Bronn, 1862
Subfamily:	Retichonetinae	Muir-Wood, 1962
Genus:	*Retichonetes*	Muir-Wood, 1962
	Retichonetes sp.	

(Plate 4.6, Figs. 2a-c)

Material: Twenty-eight specimens of brachial valves, mostly in good condition but some with broken edges.

Description: The shell is small to medium size for the genus and subcircular in outline. The brachial valve is convex posteriorly. The deltidium and interarea are present. The hinge line is straight with the length about two-thirds of the shell width.

The ribs are fine and the growth lines are distinct. The spinules are not preserved.

The reticulation feature which has been mentioned for the genus has not been observed within the specimens under consideration.

Occurrence: The genus *Retichonetes* has been reported from the Lower Devonian to Lower Carboniferous formations in Europe, Asia, western Australia and North America (Moore, 1965). In Kerman it was found with other brachiopods, e.g. *Eobrachythyris struniatus*, indicating a Famennian age.

Localities: Hutk section, level 230 m, sample BD9070; Shams Abad, level 200 m, sample BD9071; Tizi section, level 190 m, sample Tb68; and Nedenu section, level 425 m, sample Nb38.

Family: Productellidae Schuchert and LeVene, 1929

Subfamily: Productellinae Schuchert and LeVene, 1929

Genus: *Praewaagenoconcha* Sokolskaya, 1948

Praewaagenoconcha sp.

(Plate 4.6, Figs. 4a-b)

Material: Nine specimens of pedicle valves, three in mediocre condition and six partly broken.

Description: The shell is small to medium size for the genus and subcircular in outline. Maximum width appears on the posterior region.

The pedicle valve is convex posteriorly with spreading flanks. The umbo is curved but insufficient to cross the hinge line. The sulcus is not well defined. The deltidium is convex and the interarea is narrow.

Ornament is formed by fine scattered spines on the valve surface. The spines are suberect. The growth lines are fine.

Occurrence: *Praewaagenoconcha* has been reported from the Upper Devonian formations in Europe and Asia (Moore, 1965, p. H464). It was found with *Ripidiorhynchus kotalensis*, indicating a Famennian age in Kerman.

Locality: Hutk section, level 140 m, sample BD9072.

Family:	Meekelidae	Stehli, 1954
Subfamily:	Meekelinae	Stehli, 1954
Genus:	*Schellwienella*	Thomas, 1910
	Schellwienella percha	Stainbrook, 1947

(Plate 4.6, Figs. 3a-b)

Material: Five specimens of pedicle valves with broken edges.

Description: The pedicle valve is subcircular in outline, convex posteriorly and medium to large in size for the genus. The umbo is well developed and rather distorted. The hinge line is nearly equal to the maximum width of the shell. The ribs are fine and numerous. The growth lines are well developed.

Occurrence: *Schellwienella percha* is known in the Famennian formations in Afghanistan (Brice, 1971).

Locality: Hutk section, level 245 m, sample BD9073-9074.

Subfamily: Chonopectinae — Muir-Wood and Cooper, 1960

Genus: *Whidbornella* — Reed, 1943

Whidbornella productoides (Murchison, 1840)

(Plate 4.6, Figs. 5a-b)

Material: Two pedicle valves, in mediocre condition.

Description: The shell is of small size for the genus and subcircular in outline. It is almost convex posteriorly.

The umbo is projecting but the sulcus is not well defined.

Ornament is formed of scattered and suberect spines on the spine ridges. The growth lines are well defined, covering almost the entire surface.

Occurrence: *Whidbornella productoides* is common in Europe (France and Belgium) and in Afghanistan as a Frasnian species (Brice, 1971).

Locality: Hutk section, level 16 m, sample BD9075.

4.3.5 Order:	Terebratulida	Waagen, 1883
Suborder:	Terebratullidina	Muir-Wood, 1955
Superfamily:	Cryptonellacea	Thomson, 1962
Family:	Cryptonellidae	Thomson, 1962
Genus:	*Cryptonella*	Hall, 1861
	Cryptonella tripliata	Nalivkin, 1937

(Plate 4.6, Figs. 6a-e)

Material: Five specimens in relatively good condition, only partly decorticated.

Description: The shell is of small size for the genus, biconvex and subelliptical in outline. The fold and sulcus are very low in relief to absent.

The pedicle valve has a well developed umbo, projecting over the hinge line. The sulcus has small appearance near the anterior margin. The deltidium and interarea are very small.

The brachial valve has a low fold which is slightly inflated posteriorly.

No costae are present but growth lines are well developed.

Occurrence: *Cryptonella* has been reported from the Lower Devonian formations in Europe and North America (Moore, 1965). However, Brice (1971) regarded *Cryptonella tripliata* as a Famennian species in southwest Afghanistan. It is regarded as of Famennian age in Kerman.

Locality: Gerik section, level 162 m, sample BD9077.

4.4 STRATIGRAPHICAL SIGNIFICANCE OF THE BRACHIOPODS

The brachiopods from northern Kerman province generally indicate Late Devonian ages, but only thirteen taxa fall into Frasnian and eighteen taxa fall into Famennian assemblages. The Frasnian stage has also been confirmed by other fossils, e.g. spores, acritarchs and corals (see Chapters 5 and 6). The horizons bearing the fossils are thin and few. They are important for correlation within a distance of about 50 km, even when the fossiliferous localities are far from each other. The various identified species of Kerman have small vertical ranges and generally occur within limited stratigraphic intervals. A particularly marked change in their taxonomic character takes place at about the boundary between the Frasnian and Famennian stages (see Figs. 3.2, 3.3 and 3.5). At the beginning of the Famennian both in the Hutk and Shams Abad sections there is a sudden increase in the numbers of Rhynchonellida, whereas Spiriferida show a marked decrease in numbers. The Rhynchonellida preferred the shallow and turbulent water, whilst the Spiriferida lived in the deeper and quieter regions (Fürsich and Hurst, 1974). A large increase in brachiopod debris also was found at the base of the Famennian. These changes of the faunas may be related to the mass extinction and/or transgression-regression events that occurred in the Late Frasnian and Early Famennian respectively (Goodfellow et al., 1988).

McGhee and Sutton (1981), in their study of Late Devonian marine ecology and zoogeography of the central Appalachians and New York, recognized three benthic marine brachiopod communities. Most (75%) of the genera which they referred to the inner platform and nearshore environment were also found in Kerman. Based on the above comparative studies and the brachiopod assemblages, a shallow turbulent to subturbulent and benthic environment is suggested for the Kerman area. The subturbulent and agitated environment is also indicated by the sparse fauna, the individual disarticulated material and the shell debris throughout the Frasnian strata. A marked increase in the brachiopod debris at the base of Famennian successions possibly reveals a regression near the Frasnian/Famennian boundary. Within the Middle and Upper Famennian sediments specimens commonly occur as articulated brachiopods and indicate a relatively quiet water and restricted environment.

In general, Upper Devonian formations in Kerman are comparable to those of central and northern Iran. Most of the brachiopods from the study area are common and similar to those diagnostic forms that have been reported from northern and central Iran and Afghanistan (see table 2.1).

The Hutk section, with its abundant and diverse brachiopods, miospores and acritarchs, represents a classic stratigraphic unit for the Upper Devonian stratigraphy in Kerman.

Plate 4.1

Fig. 1. *Cyphoterorhynchus arpaensis* (Abramian, 1957).
1a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Frasnian, sample BD9033.

Figs. 2 & 3. *Paurorhyncha bikniensis* Gaetani, 1965.
2: pedicle valve ×1.5, sample MDH1376; 3: pedicle valve ×1, Famennian, sample BD9031.

Fig. 4. *Ptychomaeltoechia deltidialis* Gaetani, 1965.
4a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Famennian, sample BD9035.

Fig. 5. *Ptychomaletoechia elburzensis* Gaetani, 1965.
5a-d: brachial valve, pedicle valve, posterior, lateral, all ×1, Famennian, sample BD9037.

Fig. 6. *Rhipidiorhynchus kotalensis* Brice, 1971.
6a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1.5, Famennian, sample BD9039.

Fig. 7. *Anathyris* sp. Von Peetz, 1901.
7a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×3, Frasnian, sample BD9041.

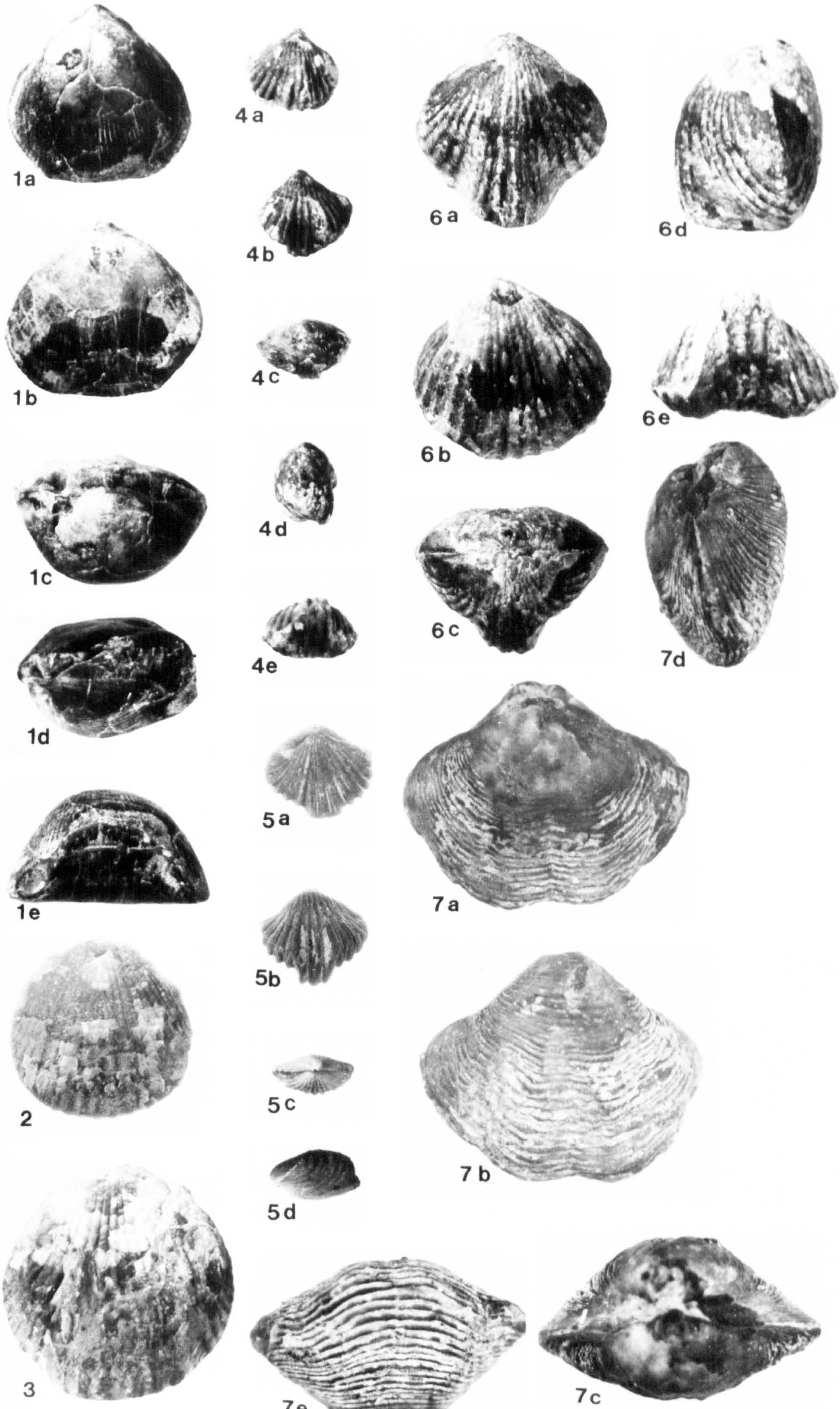
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Plate 4.2

Fig. 1. *Athyris chitralensis* Reed, 1922.
1a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×2, Frasnian, sample BD9042.

Fig. 2. *Composita* sp. Brown, 1849.
2a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1.5, Famennian, sample BD9047.

Fig. 3. *Spinatrypina chitralensis* (Reed, 1922).
3a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×2, Frasnian, sample BD9050.

Fig. 4. *Cyrtospirifer supradisjunctus* (Obrutschew, 1931).
4a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Frasnian, sample BD9057.

Fig. 5. *Cyrtospirifer (Cy.) verneuili* (Murchison, 1840)
5a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1.5, Frasnian-Famennian, sample BD9060.

Figs. 6 & 7. *Cleiothyridina reticulata* sp. Stainbrook, 1947.
both pedicle valves ×1, Famennian, samples MDH157 and MDH160.

Fig. 8. *Torynifer* sp. Hall and Clark, 1894.
pedicle valve ×1.5, Famennian, sample MDH1342.

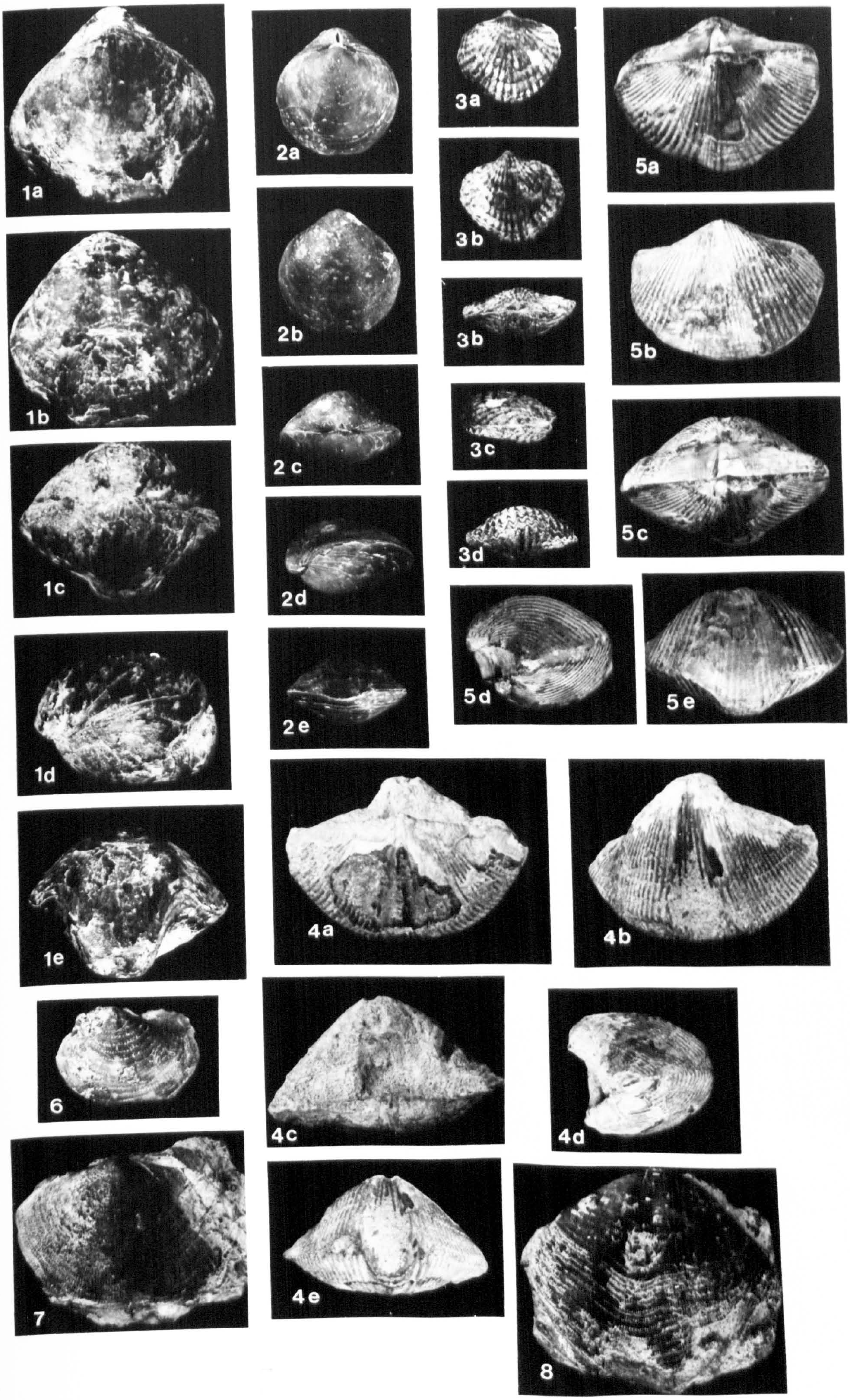
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Plate 4.3

Fig. 1. *Cyrtospirifer schelonicus* Nalivkin, 1941.
1a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1.5, Frasnian, sample BD9055.

Fig. 2. *Eobrachythyris struniatus alatus* sp. (Gosselet, 1879)
2a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Famennian, sample BD9063.

Fig. 3. *Sphenospira* sp. Cooper, 1955.
3a-b: pedicle valve, brachial valve, both ×1, Famennian, sample BD9065.

Fig. 4. *Dmitria* sp. Sidiachenko, 1961.
4a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Famennian, sample MDH1274.

Fig. 5. *Torynifer* sp. Hall and Clark, 1894.
pedicle valve ×1, Famennian, sample BD9068.

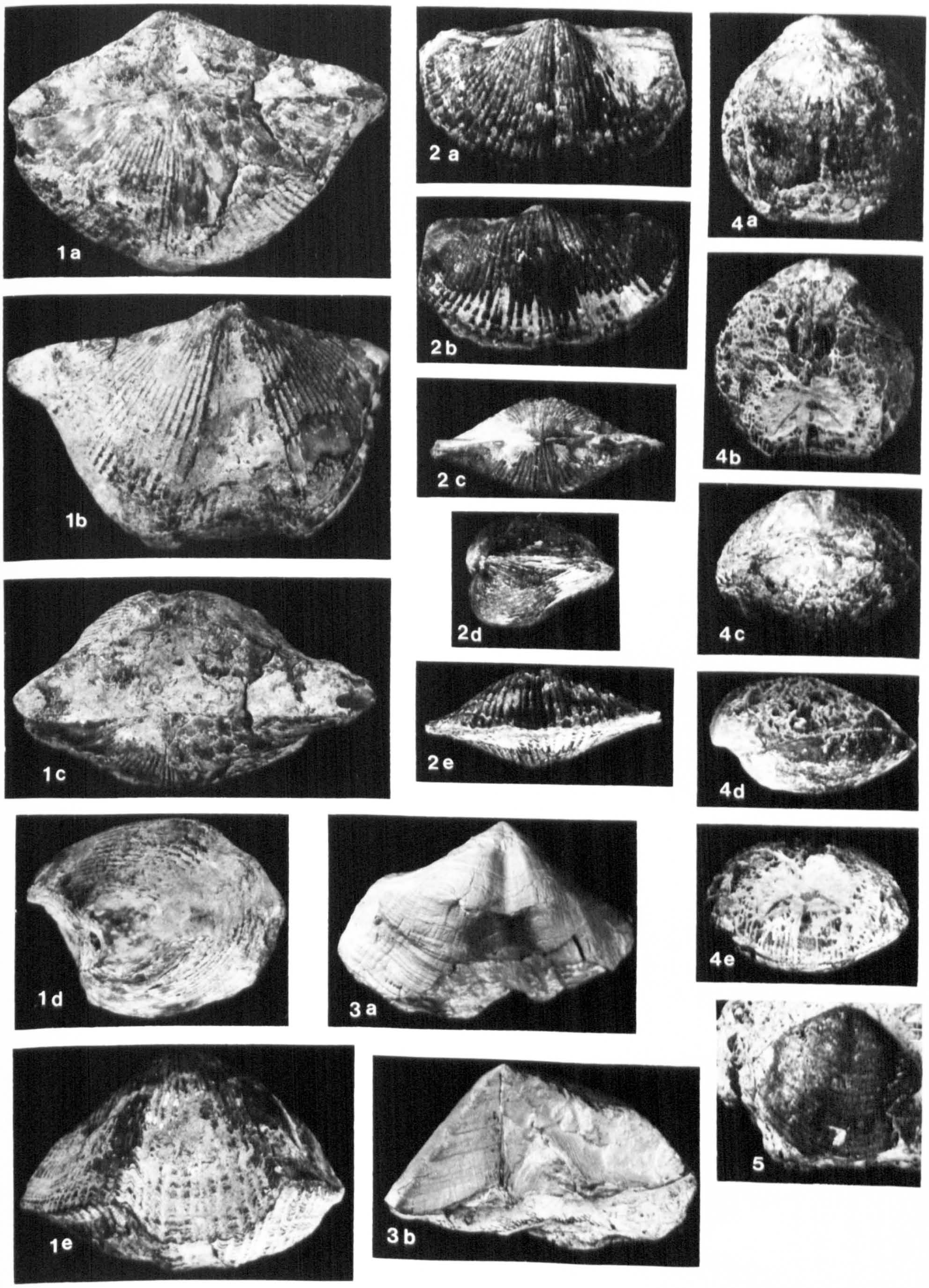
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Plate 4.4

Fig. 1. *Dichospirifer thylakistoides* (Brice, 1971).
1a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Famennian, sample BD9062.

Fig. 2. *Anatrypa* sp. Nalivkin, 1941.
2a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, Frasnian, sample BD9049.

Fig. 3. *Spinatrypina robusta* sp. Copper, 1967.
3a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×2, Frasnian, sample BD9052.

Fig. 4. *Cliothyridina coloradensis* sp. (Girty, 1900).
4a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×3.33, Famennian, sample BD9044.

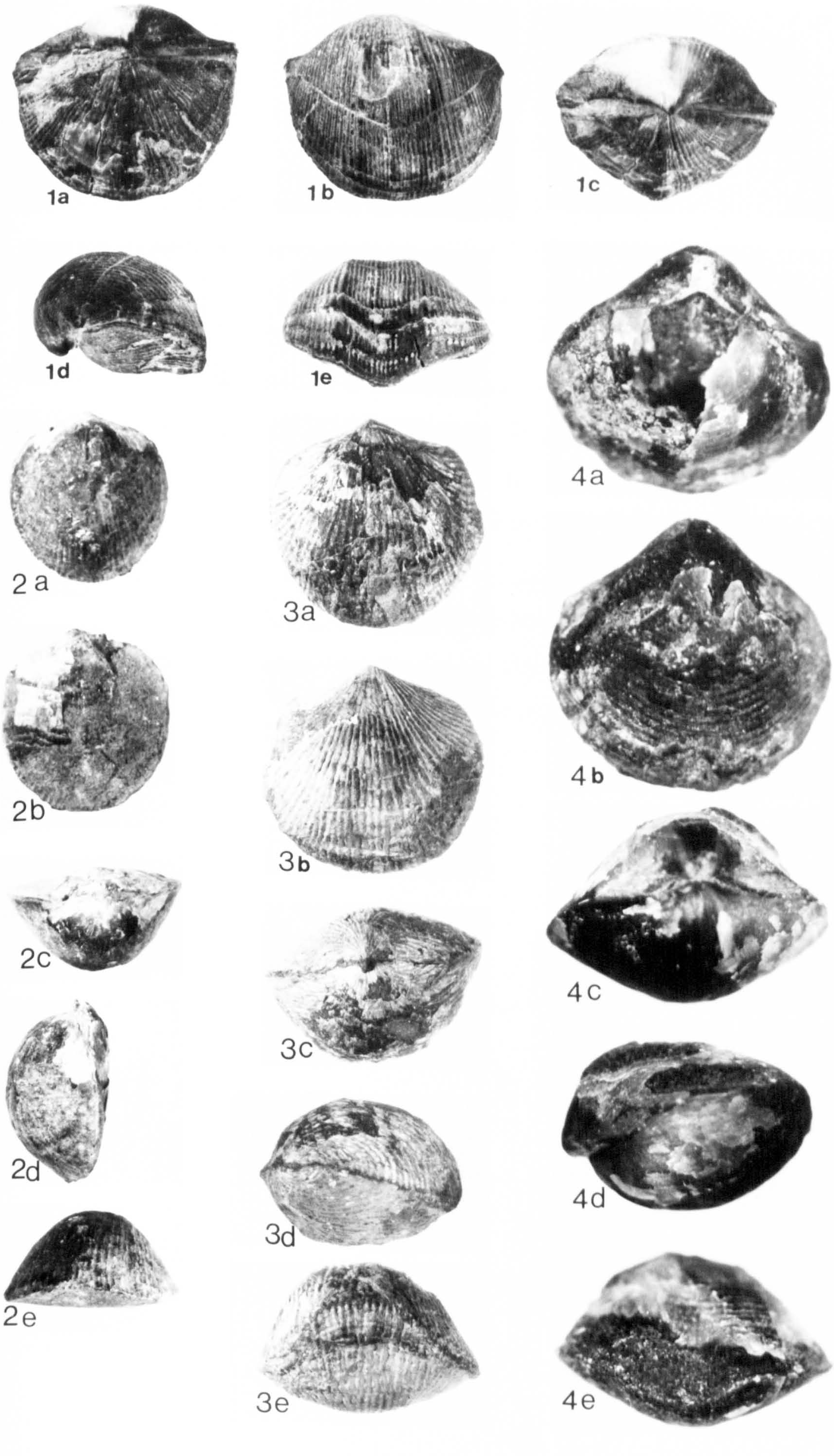
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Plate 4.5

Fig. 1. *Cyrtospirifer asiaticus* Brice, 1971.
1a-d: brachial valve, pedicle valve, lateral, anterior, all ×1, Famennian, sample BD9054.

Fig. 2. *Cyrtospirifer (Cy.) Syringothyriformis* Paeckelmann, 1942.
2a-d: brachial valve, pedicle valve, lateral, anterior, all ×1, Famennian, sample BD9059.

Fig. 3. *Uchtospirifer multiplicatus* sp. Brice, 1971.
3a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×1, 3f lower right of brachial valve ×5, Frasnian, sample BD9066.

Fig. 4. *Tylothyris subvaricosa* sp. (Hall and Whitfield, 1872).
4a-d: brachial valve, pedicle valve, posterior, anterior, all ×4, Frasnian, sample BD9069.

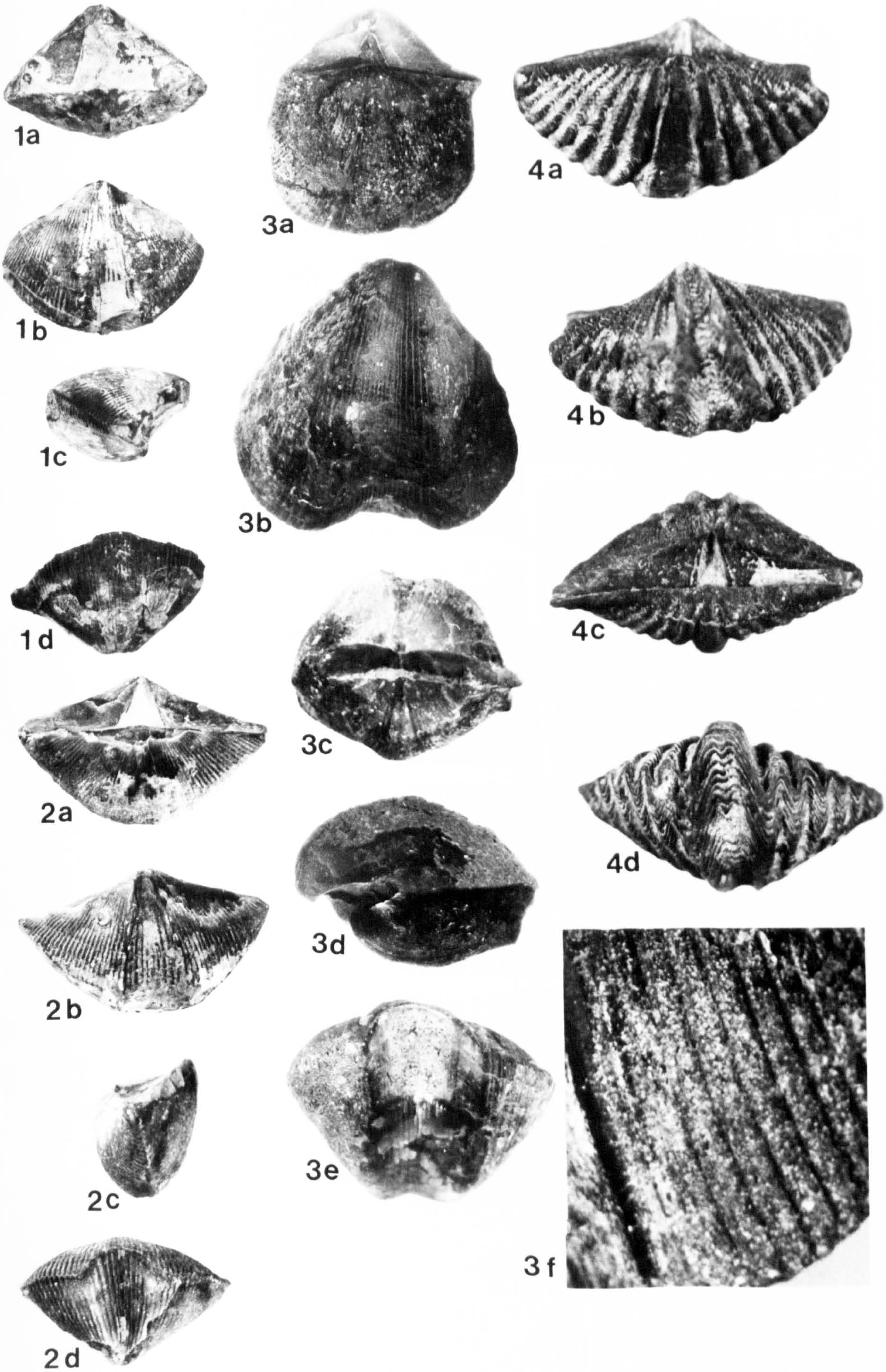
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Plate 4.6

Fig. 1. *Leptaena* sp. Dalman, 1828.
1a-b external brachial valve, pedicle valve, both ×1, Famennian, sample BD9069.

Fig. 2. *Retichonetes* sp. Muir-Wood, 1962.
2a-b: brachial valve, pedicle valve, both ×2; 2c: faunas within the rock sample ×.5, Famennian, sample BD9070.

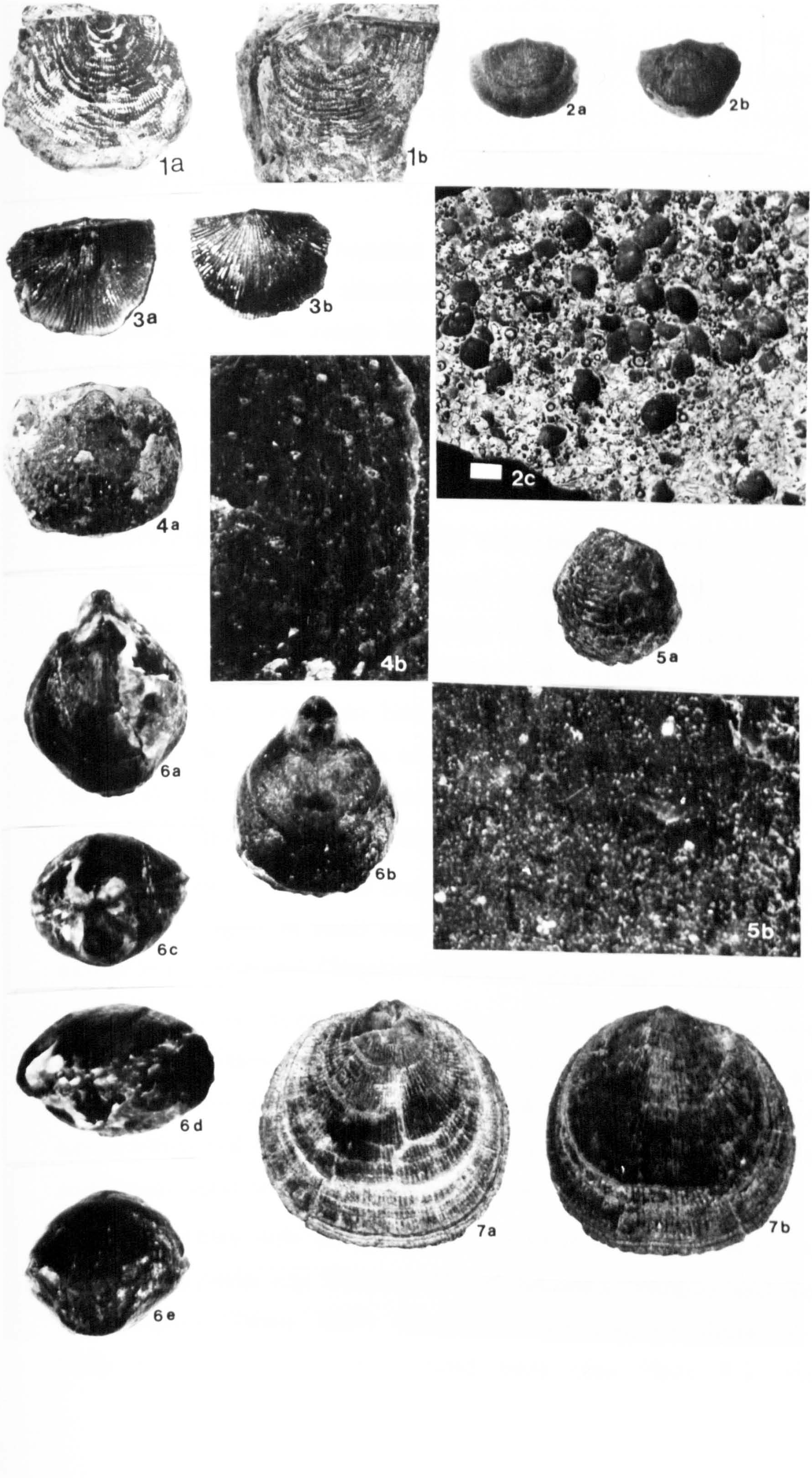
Fig. 3. *Schellwienella percha* Stainbrook, 1947.
3a-b: pedicle valves (internal and external), both ×1.5, Famennian, sample BD9073.

Fig. 4. *Praewaagenoconcha* sp. Sokolskaya, 1948.
4a: pedicle valve ×1; 4b: lower left ×5, Upper Devonian, sample BD9072.

Fig. 5. *Whidbornella productoides* (Murchison, 1840)
5a: pedicle valve ×1.5; 5b: lower left ×5, Frasnian, sample BD9075.

Fig. 6. *Cryptonella tripliata* sp. Nalivkin, 1937.
6a-e: brachial valve, pedicle valve, posterior, lateral, anterior, all ×2, Famennian, sample BD9077.

Fig. 7. *Rhipidomella* sp. Oehlert, 1890.
7a-b: brachial valve, pedicle valve, both ×2, Famennian, sample BD902.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CHAPTER 5

FRASNIAN CORALS

5.1 INTRODUCTION

Evolution of the Frasnian rugose corals was very rapid; thus they are useful for coral zonation, correlation and palaeoenvironmental interpretation. The range chart of the Frasnian rugose corals of the world by Sorauf and Pedder (1986) shows that many taxa, e.g. *Disphyllum* sp. are restricted to the conodont zones triangularis and gigas (Late Frasnian) and extinguished before Famennian time. Tsien (1978) suggested that the Givetian and Frasnian coral zonations in Belgium and northern France may be correlated with the refined conodont zonation.

The corals described below were collected by the writer in the course of sampling for stratigraphical study of the Devonian rocks in the northern part of the Kerman region. No previous palaeontological work on the corals from this area has been done, in spite of their abundance near Gerik Village, about 75 km north of Kerman Town (Fig. 3.1). Some of the corals found in Kerman are also reported from the Alborz Mountains, in northern Iran (Ghods, 1982).

Upper Devonian rocks crop out in a mountainside about 350 m west of Gerik Village. A coral reef 4-6 m thick and about 80 m in lateral extent is present (see Chapter 3 for stratigraphical details).

Disphyllum caespitosum dominates the fauna and is accompanied by numerous solitary corals, bryozoans, brachiopods and a few gastropods. The fossils are generally well preserved in muddy limestone and can be easily extracted from the matrix. Only in some parts are the specimens commonly distorted due to diastrophism.

Stromatoporoids are usually associated within the coral community in many regions, e.g. Ontario, North America (Hodges and Roth, 1986) and Belgium (Tsien, 1967). However, they were not found in this unit. Only one alga fossil was found here (see Plate 5.4, Figs. 2a-b).

Disphyllum caespitosum from the West Falls Group (southwest New York) accumulated in storm deposits (Sorauf, 1987), where it is not accompanied by stromatolites. Shallow, clear and agitated sea water is particularly favorable to the development of the massive stromatoporoids (Tsien, 1967). Nevertheless, the corals preserved in this section lived in muddy environments. Thus the environmental conditions possibly were unfavorable to the development of stromatoporoids.

The attitude of the fossils is commonly described as being "in situ", "in growth position", etc. Orientation of corals and stromatoporoids in some Pleistocene, Devonian and Silurian reef facies in many outcrops of North America, e.g. Florida (Pleistocene) and Ontario (Devonian) were studied by Hodges and Roth (1986). Their measured percentages of upright corals and stromatoporoids range from 80% to 95%. However, Kobluk et al. (1977) found upright percentages between 31% and 69% from three coral horizons of North America (Manitoulin, Miette and Jamesville).

Disphyllum caespitosum faunas at Gerik show an upward orientation between 60% to 65%, with dendroid habit, and are possibly in their growth location. Individual *Hexagonaria hexagona* are oriented randomly; thus they were transported to their present locality. *Disphyllum* sp. and *Hexagonaria hexagona* have been exposed within the Frasnian succession in the Hutk outcrop, about 50 km to the south, and the Shams Abad outcrop, approximately 65 km southwest, of the Gerik section. They form a 30 to 40 cm thick bed there. It is likely that the corals in the Hutk section are in their growth position, whereas the corals in the Shams Abad section were transported.

About 35% to 45% of the fossils are oriented vertical to the bedding planes, suggesting core reef facies; other reef facies were not determined here.

Disphyllum generally lived in a shallow water environment. It was sensitive to environmental changes and possessed different external forms in different facies (Tsien, 1967). The external form of the corallum of *Disphyllum caespitosum* is fasciculate dendroid, indicating that the specimens grew in a sub-turbulent environment.

The formation of the reef facies took place in shallow water. Overlying the reef facies are thick limestone beds containing many large brachiopods, e.g. *Uchtospirifer*, indicating a relatively deeper environment. The upper surface of the coral beds is irregular. It is likely that further subsidence terminated the development of the reef and killed almost all corals.

Ghods (1982) described ten coral taxa from the Frasnian formations of northern Iran. Four of the taxa (*Disphyllum* sp., *Disphyllum caespitosum*, *Hexagonaria hexagona* and *Macgeea*) also occur in Kerman. A marked difference between the faunas from these two areas (about 1200 km apart from each other) is that individual specimens are scattered throughout the sections in the north but they have been restricted within a 3-4 m reef horizon in Kerman.

In this study 444 specimens, including 4 taxa of rugosa and 4 taxa of Tabulata corals, were collected. The systematic classification followed is that of the *Treatise of Invertebrate Paleontology*, Part F., Vols. 1 and 2, "Coelenterata", by Teichert (1981).

210 specimens are housed in the collection of the Department of Palaeontology of the Natural History Museum, London, and 234 samples are housed in the Department of Geology, University of Shahid Bahonar, Kerman, Iran.

5.2 SYSTEMATIC PALAEONTOLOGY

Class:	Anthozoa	Ehrenbery, 1834
Subclass:	Rugosa	Milne-Edwards and Maime, 1850
Order:	Stauriida	Verrill, 1865
Suborder:	Columnariina	Soshkina, 1941
Family:	Disphyllidae	Hill, 1939
Subfamily:	Disphyllinae	Hill, 1939
Genus:	*Disphyllum*	de Fromentel, 1861
	Disphyllum sp.	

(Plate 5.1, Figs. 1a-c)

Material: Twelve specimens, the majority in good condition.

Description: The corallum is phaceloid; first-order septa are long and reach the centre. Carinae have not been seen. The septa are thick and twisted towards the periphery. Second-order septa are long with thickening within the dissepimentarium. Tabulae are flat with peripheral inclined globose plates. The axial boss is highly convex. The dissepiments are weak.

Numbers of the first-order septa range from 14 to 22 with corallite diameter from 5 to 10 mm.

Occurrence: *Disphyllum* is widespread in the Middle and Upper Devonian formations and it is especially common in the Frasnian formations in southwest New York State (Sorauf, 1987) and in west Afghanistan (Brice, 1971), and six specimens have been found in northern Iran (Ghods, 1982).

Localities: Gerik Section level 96 m, sample HC10, and Shams Abad section, level 15 m, sample R53797.

Disphyllum caespitosum (Goldfuss, 1826)

(Plate 5.2, Figs. 1a-d)

Material: 300 specimens, mostly in good condition.

Description: The corallum is irregular, fasciculate (phaceloid). Corallite is long, generally cylindrical and has a thick wall. Both septa and dissepiments show thickening towards the peripheral. First-order septa are thin at the axial ends. Thickening of the septa begins at about their centre and increases toward the periphery. The thickening of the dissepiments may extend to the inner wall.

In transverse section, the corallites display radially arranged attenuate septa in two orders. First-order (major) septa reach the axial region of the corallite. Second-order septa do not extend into the tabularium but terminate in the innermost dissepimentarium. Length of the second-order septa is about one-third of the first-order septa. The axial structure has not been seen.

Number of first-order septa ranges from 20 to 24 and the corallite diameter from 7 to 12 mm. The mean diameter for 14 corallites examined was 8.3 mm and the mean number of first-order septa was 22.5.

In longitudinal section the specimen has 2-3 rows of dissepiments which are globose in shape with generally thicker wall near the periphery of the corallite.

The tabularium is composed of flat to slightly inclined axial tabulae. The tabulae are arranged around the axial region.

Occurrence: *Disphyllum caespitosum* is the most common Frasnian coral in the West Falls strata of southwestern New York (Sorauf, 1987). It has also been recorded as a Frasnian species in south Devonshire, England (Murray, 1985, p. 25) and fifteen specimens have been identified in the Khoshyeilagh section, north Iran (Ghods, 1982).

Locality: Gerik Section level 96-102 m, samples R53798-R53801.

Subfamily: Hexagonarinae Bulvanker, 1959

Genus: *Hexagonaria* Gurich, 1896

Hexagonaria hexagona Goldfuss, 1826

(Plate 5.2, Figs. 2a-c; Plate 5.4, Fig. 3)

Material: Twelve specimens, almost in good condition.

Description: The corallum is cerioid. The septa are fusiform and long with radial arrangement in transverse section. First-order septa attenuate in the tabularium and meet at the axis. They also show slight thickening in the inner part of the dissepimentarium.

The length of the second-order septa is about one-half of the first-order septa. The number of first-order septa ranges from 18-22 with corallite diameter of 10-15 mm.

The dissepiments are small, numerous (4-8 rows) and subglobose, steeply sloping adaxially towards the tabularium. The tabulae are concave.

Dissepimentarial floors are slightly declined outward near the peripheral margin and steeply declined adaxially near the inner margin of dissepimentarium. The trabeculae are weak with asymmetrical arrangement.

Occurrence: The earliest appearance of *Hexagonaria hexagona* has been regarded as the lower limit of the Frasnian in the Rhenish Mountains of western Germany by Birenheide (1988). It is also reported from the Frasnian formations in north Iran (Ghods, 1982), Belgium (Tsien, 1967) and Afghanistan (Brice, 1971).

Localities: Gerik Section level 96-100 m, samples R53802 and R53803, and Shams Abad section, level 15 m, sample Shc10.

Family:	Phillipsastreidae	Hill, 1954
Genus:	*Macgeea*	Webster, 1889
	Macgeea ponderosa	Stumm, 1960

(Plate 5.2, Figs. 2a-c)

Material: Forty-five specimens, mostly in good condition.

Description: The corallum is subcylindrical. The epitheca is fine, covering the surface of the corallum. The septa are commonly spindle-shaped and dilated in the dissepimentarium which is attenuated in the tabularium. The septa generally do not reach the axis of the corallite, rather the axis is open. The septal ridges are developed.

In transverse section, the septa are generally radially arranged. They are numerous (about 67) with both first and second-order form. The length of the second-order septa is about one-third of the first-order septa. The number of first-order septa ranges from 20 to 46 and the corallite diameter from 12 to 24 mm. Mean diameter of seven corallites examined was 16.4 mm and the mean number of first-order septa was 31.

In longitudinal section, tabulae are present in the axial region, with both complete and incomplete appearance. They are convex. Dissepiments consist of two rows which are slightly dilated toward the periphery.

Occurrence: *Macgeea ponderosa* has been reported from the Frasnian West Falls Group in southwest New York (Sorauf, 1987), north Iran (two specimens, Ghods, 1982) and west Afghanistan (Brice, 1971).

Locality: Gerik Section level 98 m, samples R53805-R5807.

Subclass:	Tabulata	Milne-Edwards and Haime, 1850
Order:	Chaetetida	Okalitch, 1936
Family:	Chaetetidae	Milne-Edwards and Haime, 1850
Subfamily:	Chaetetinae	Milne-Edwards and Haime, 1850
Genus:	*Chaetetes*	Waldheim in Eichwald, 1829
	Chaetetes sp.	

(Plate 5.3, Figs. 2a-b)

Material: Only one sample, almost in good condition.

Description: The corallite is ceratoid to subtrochoid in outline. The corallite wall is thin. Septa are lacking but numerous imperforate polygonal pores are present. The tabulae are not seen.

Occurrence: *Chaetetes* sp. has been reported from the ?Silurian and Middle Devonian to Carboniferous formations in Europe, Asia and North America (Teichert, 1981, p. F509). In the Gerik section it was found within the Frasnian coral community containing *Disphyllum caespitosum*.

Discussion: *Chaetetes* has also been referred to as the order Sclerospongidea in the literature (Murray, 1985). Since only one specimen has been identified in an otherwise predominently coral fauna, the writer prefers not to debate the affinities of the organisms, but accepts here the early classification.

Locality: Gerik Section level 98 m, sample R53808.

Order:	Favositida	Wedekind, 1937
Suborder:	Alveolitina	Sokolov, 1950
Family:	Alveolitidae	Duncan, 1872
Subfamily:	Alveolitinae	Duncan, 1872
Genus:	*Alveolites*	Lamarck, 1801
	Alveolites sp.	

(Plate 5.3, Figs. 3a-d)

Material: Nine samples, mostly in good condition.

Description: The corallum is subcylindrical with irregular outgrowth in outline. The corallites are long and curved. The calices are oblique with irregular angularity. The walls are thin in the basal part but thicker elsewhere. The mural pores are well developed on the surface of the corallites and show a wavey structure to both longitudinal and cross sectional surfaces. The septal spines are not well defined. The tabulae are thin but complete and increases laterally.

Occurrence: *Alveolites* is a cosmopolitan genus in Lower, Middle and Upper Devonian formations (Teichert, 1981, p. 591). It has been reported from the Upper Frasnian in Belgium (Tsien, 1978).

Locality: Gerik Section level 97 m, samples R53809-R53811.

Family:	Micheliniidae	Waagen and Wentzel, 1886
Subfamily:	Micheliniinae	Waagen and Wentzel, 1886
Genus:	*Michelinia*	De Koninck, 1841
	Michelinia sp.	

(Plate 5.2, Figs. 3)

Material: Only one sample, not well preserved.

Description: The corallum is cerioid. The corallites are polygonal and have thick walls. Internal structures have been lost by recrystallization.

Occurrence: *Michelinia* has been found within formations ranging from Lower Devonian to Upper Permian in Europe, North Africa, Asia, Australia and North America (Phillips, 1936, in Teichert, 1981, p. 561). It was also reported from the Upper Devonian formations in the Ural-Tienshan and Djungar-Balchashian provinces of southeastern USSR (Dubatolov and Spassky, 1967, p. 508).

Locality: Gerik Section level 98 m, sample R53812.

Superfamily:	Pachyporicae	Gerth, 1921
Family:	Pachyporidae	Gerth, 1921
Genus:	*Thamnopora*	Steininger, 1831
	Thamnopora sp.	

(Plate 5.4, Figs. 1a-c)

Material: Sixty-one specimens, mostly in good condition.

Description: The corallum is ramose with cylindrical to subcylindrical branches. The corallite is rounded to subrounded in section but diverges from the branch axes. It is open and perpendicular to the surface. The corallites have relatively thin walls. The tabulae are thin and few in number but are widely spaced.

Septal spines are rare but numerous mural pores are present. The pores within the walls are large and circular and are arranged in longitudinal rows on the surface. The distance between them is about 2 to 3 mm.

The majority of the fragmentary branches measured are between 15 to 20 mm in diameter.

Occurrence: *Thamnopora* is known in the Odoiskaya Suite and Middle to Upper Devonian formations in the Far East and Transbaikal region, USSR (Modzalevskaya, 1967) and Upper Devonian formations of Western Australia (Roberts et al., 1967).

Locality: Gerik Section level 96-100 m, samples R53813 and R53814.

Plate 5.1 Figs. 1a-c: *Disphyllum* sp.

1a, lateral view; 1b, transverse section ×4; 1c, longitudinal section ×4.

Frasnian, samples R53796 and R53797.

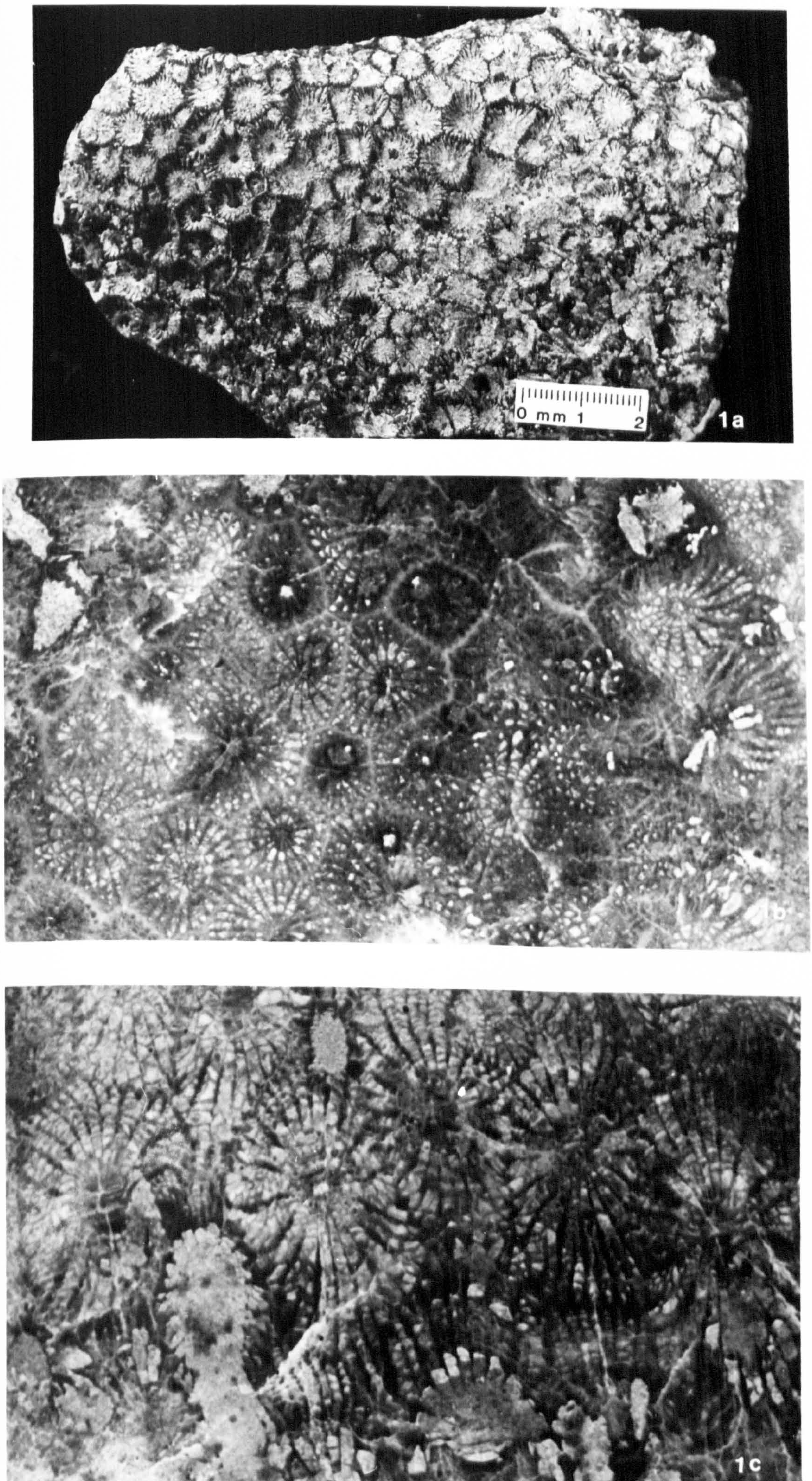
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Plate 5.2 Figs. 1a-d: *Disphyllum caespitosum.*

1a and 1d, longitudinal sections ×4; 1b-c, transverse sections ×4.

Frasnian, samples R53798-R53801.

Figs. 2a-c: *Hexagonaria hexagona.*

2a, lateral view; 2b, transverse section ×1.75; 2c, longitudinal section ×1.75.

Frasnian, samples R53802-R53803.

Fig. 3: *Michelinia* sp.; ×1.

Frasnian, sample R53812.

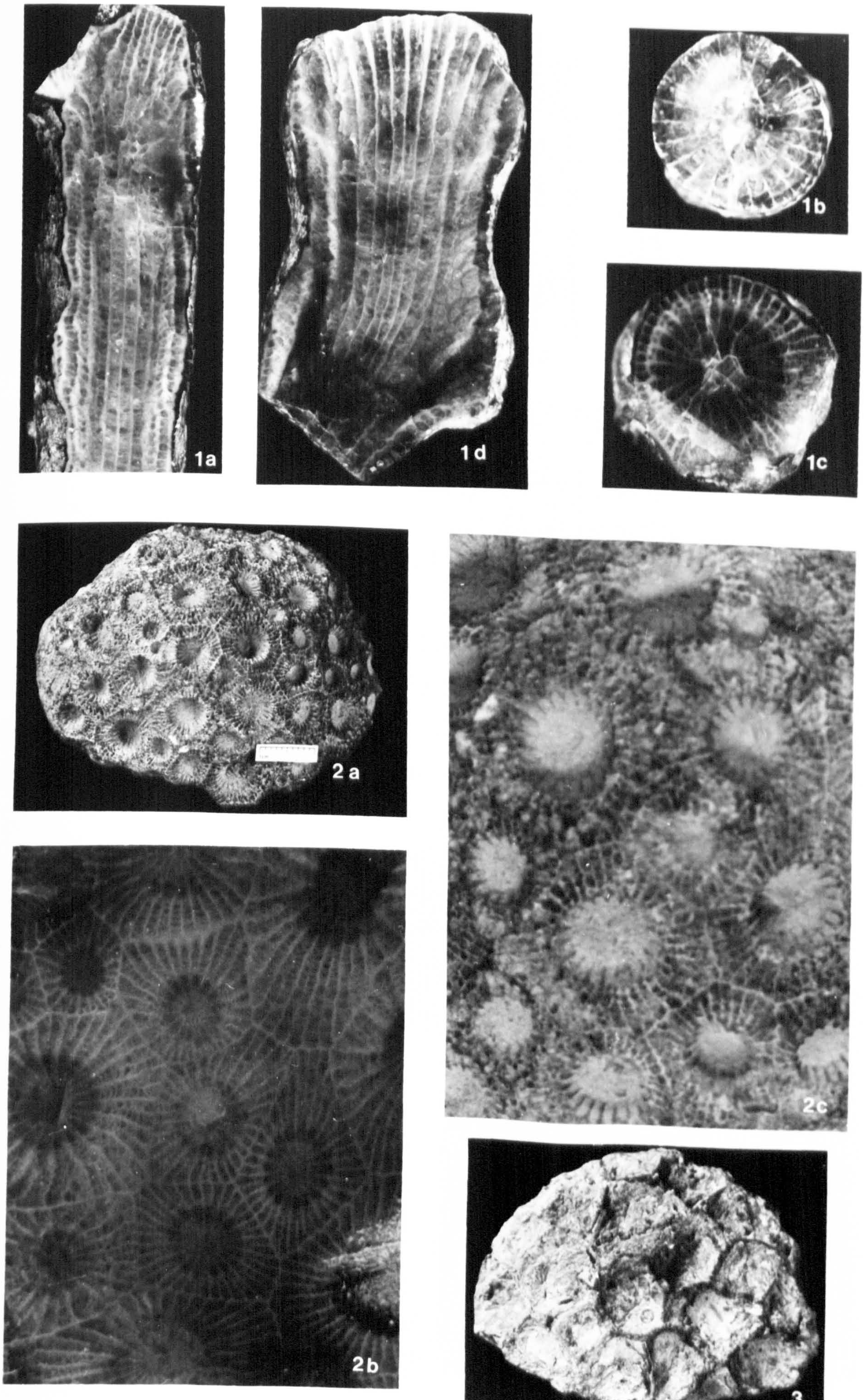
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Plate 5.3 Figs. 1a-c: *Macgeea ponderosa*.

1a, lateral view ×1.25; 1b, transverse section ×2.5; 1c, longitudinal section × 2.5.

Frasnian, samples R53805-R53807.

Figs. 2a-b: *Chaetetes* sp.

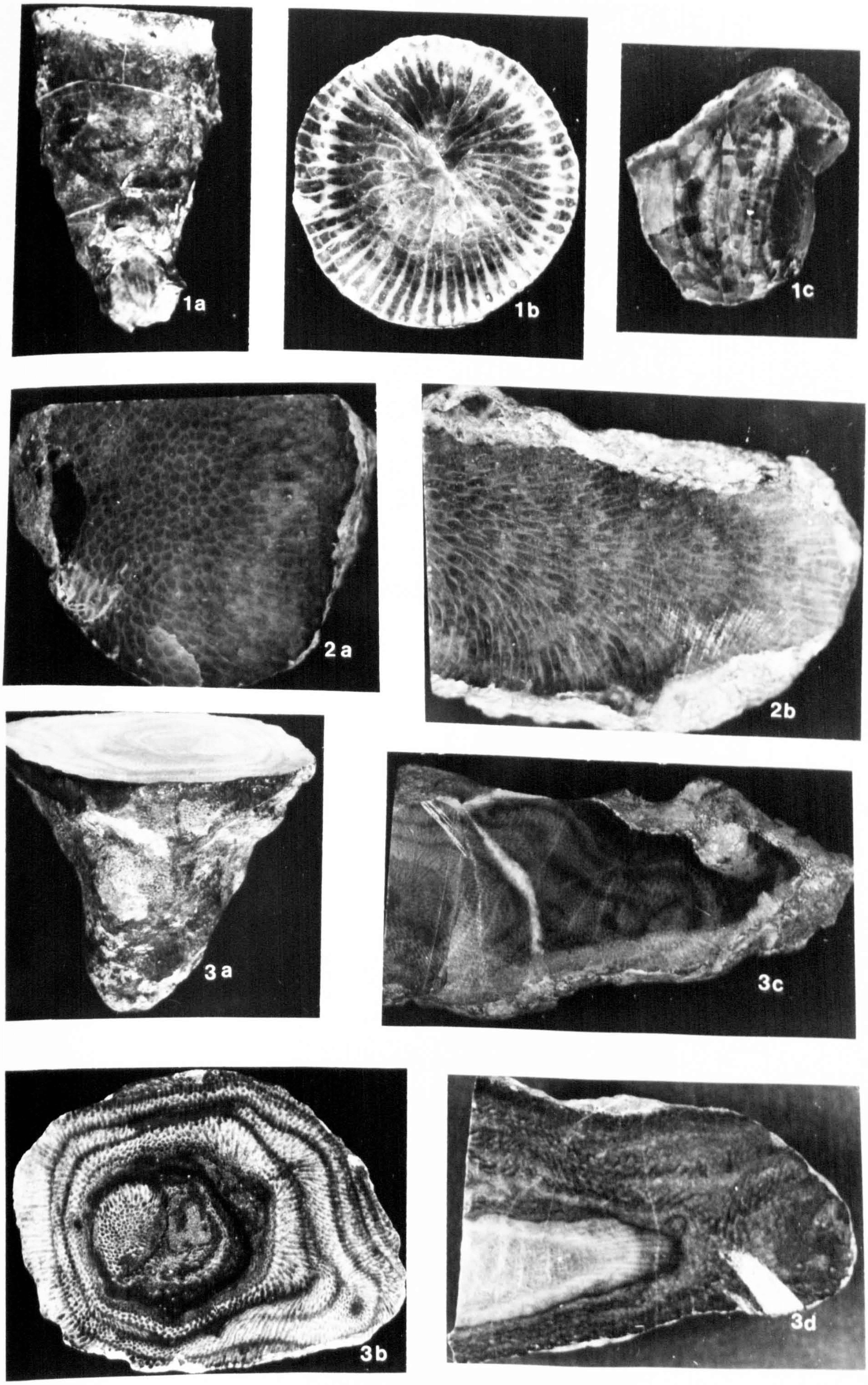
2a, transverse section ×3.5; 2b, longitudinal section ×3.5.

Frasnian, sample R53808.

Figs. 3a-d: *Alveolites* sp.

3a, lateral view ×1; 3b, transverse section ×1.33; 3c, longitudinal section ×2.33; 3d, longitudinal section ×1.

Frasnian, samples R53809-R53811.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3d

Plate 5.4 Figs. 1a-c: *Thamnopora* sp.

1a, lateral view ×3; 1b, transverse section ×4; 1c, longitudinal section ×3.

Frasnian, samples R53813 and R53814.

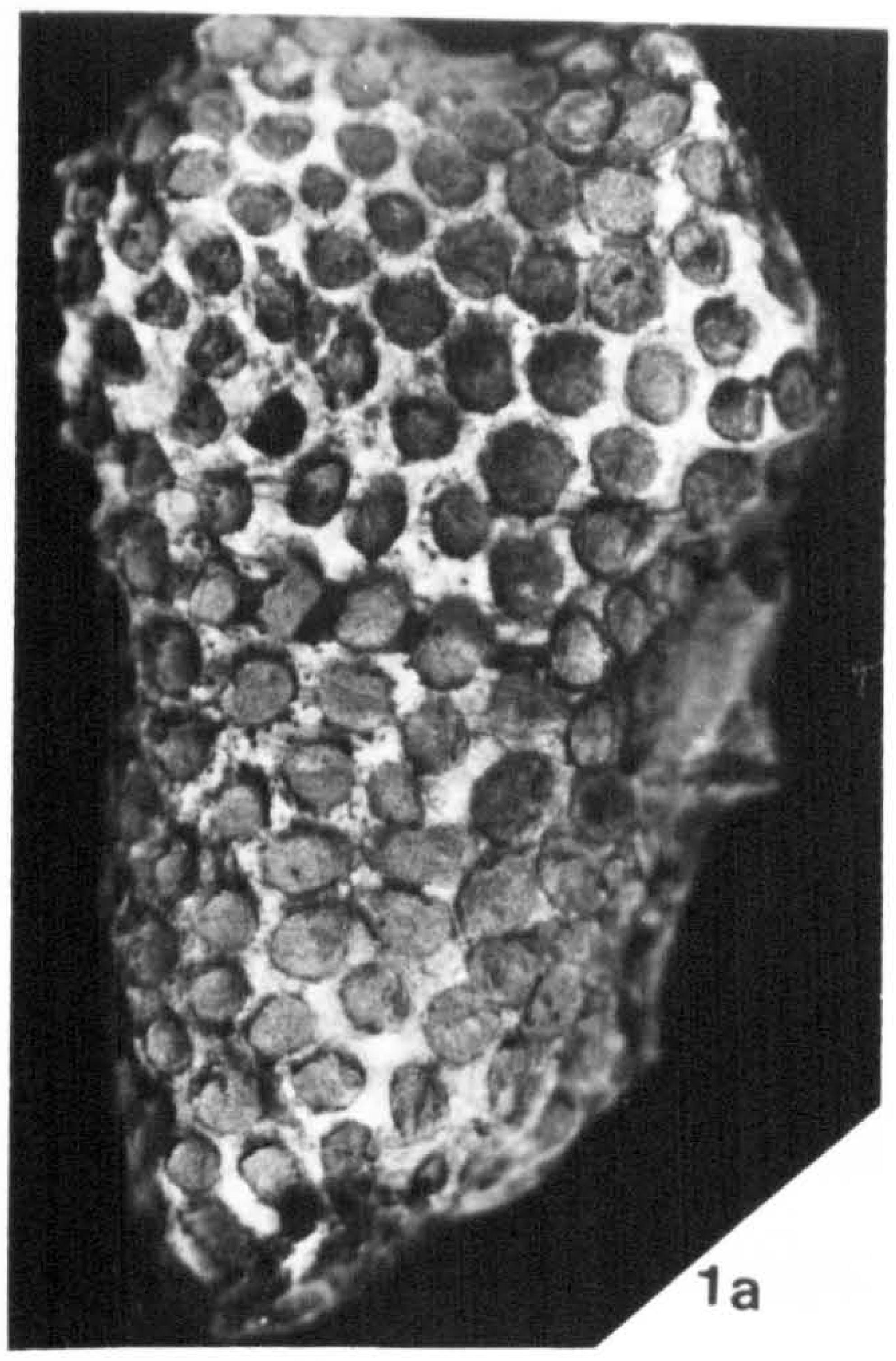
Figs. 2a-b: Algal

2a, lateral view ×3; 2b, transverse section ×3.

Sample GA20.

Fig. 3: *Hexagonaria hexagona*; lateral view.

Frasnian, sample R53804.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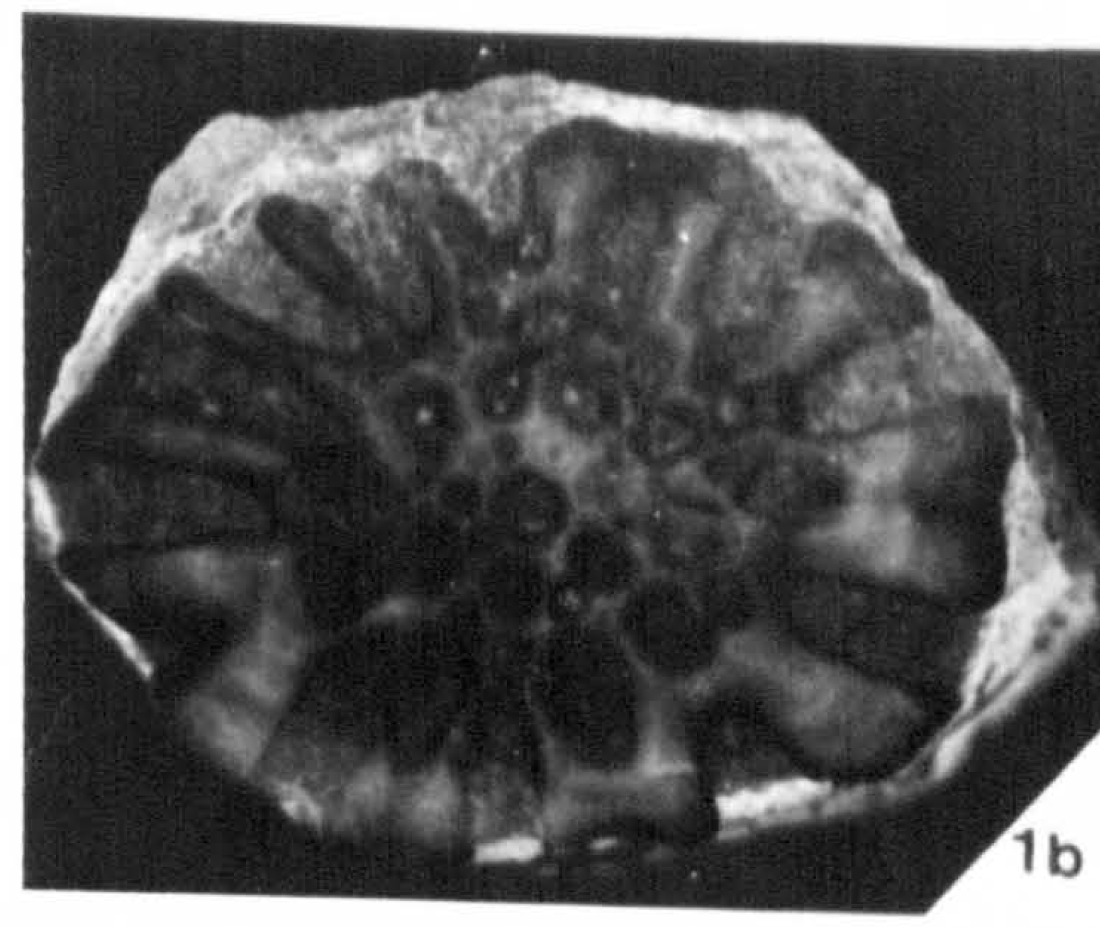
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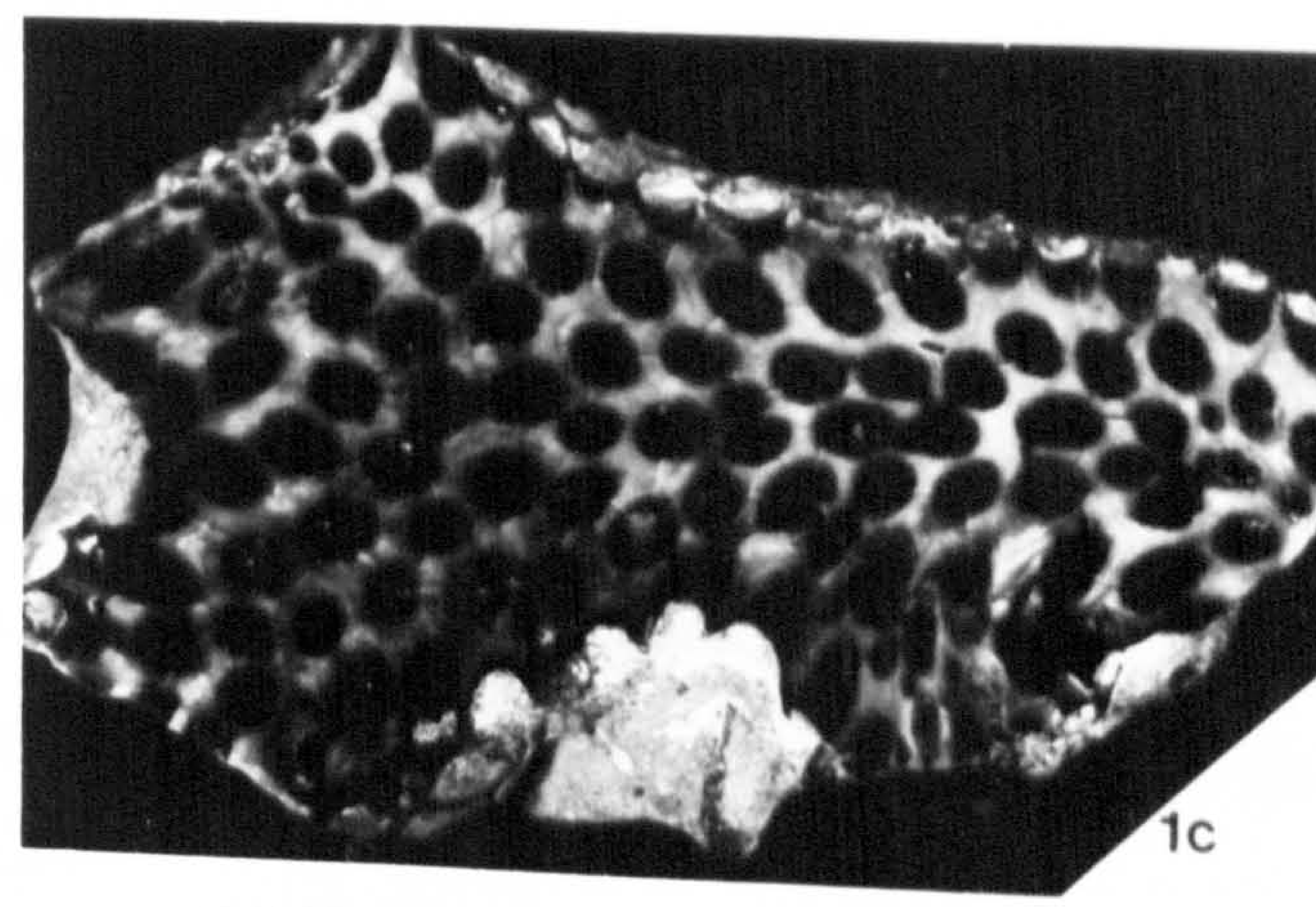
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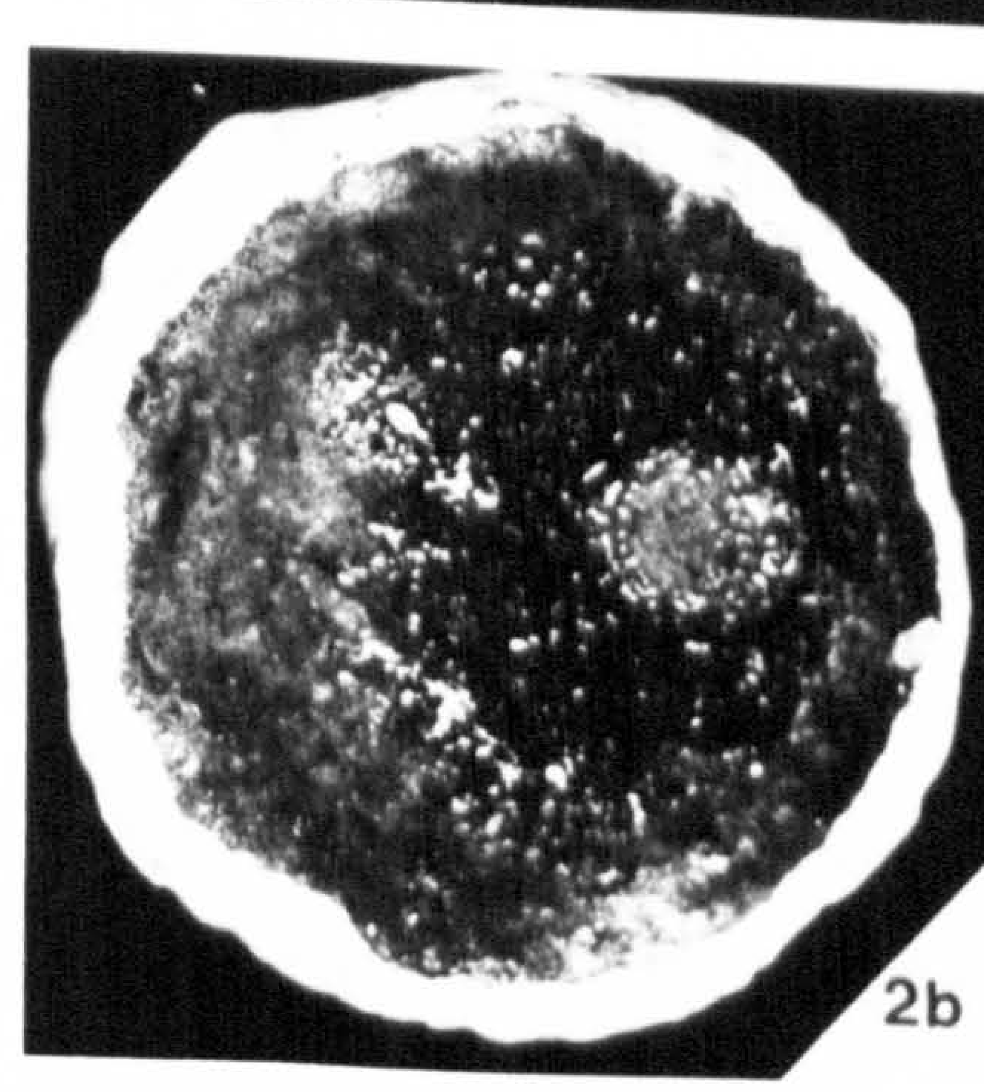
2a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CHAPTER 6

FRASNIAN ACRITARCHS AND SPORES IN KERMAN

6.1 INTRODUCTION

The past forty years have seen a phenomenal increase in the volume of palynological research, especially in biostratigraphy. Spores and acritarchs are particularly important for dating and correlating horizons and formations of different facies in distant territories (Skaya, 1988). Palynomorphs are useful for biostratigraphy because they usually are deposited in very large numbers; thus even small samples may yield sufficient quantities of spores and acritarchs to indicate statistically significant populations of particular species. Palynomorphs are rapidly distributed over wide areas which enhances their use as zonal floras; they are commonly facies-independent and are well preserved in most fine grained sedimentary rocks.

Recently spores have been used widely by many geologists for delimiting zonation and correlating the Devonian stages. Richardson and McGregor (1986) proposed the first international spore zonation for the Silurian and Devonian of the Old Red Sandstone continent and adjacent regions. Only *Geminospora lemurata* of the spore assemblage zones from the Old Red Sandstone continent was found in Kerman. Avkhimovitch et al. (1988) differentiated 24 palynozones for the Middle and Upper Devonian deposits of the Pripyat Depression, Byelorussia. Furthermore, they used the palynozones for correlating the sediments of Pripyat with the successions of the same age in the eastern European platform, western Europe and Canada. None of the spore species described by these authors has been found in Kerman and little is known about the Devonian spores there; thus the existing zonations are not applicable to the present study.

The objectives of this study were to determine the age of the strata which lack stratigraphically useful macrofossils and to establish precise age limits for the brachiopod and coral taxa. This study shows that microspores and acritarchs are abundant, diverse and commonly well preserved in Kerman.

Reducing acidic environments are the best for the preservation of spore walls. The clastic sediments which have accumulated in such environments are characteristically black, grey or green. The most palynologically productive clastic lithologies are usually black, grey or green shales and fine grained siltstones (Cross, 1964). Samples were collected from grey calcareous shales containing no obvious macrofossils. The specimens were collected mainly from the shale horizons in the lower part of five outcrops, including the Gerik, Hutk, Nedenu, Shams Abad and Tizi sections (see Fig. 3.1 for the location of sections).

The aim of sampling the lower part of the sections was to determine whether Middle Devonian strata are present. However, stratigraphic dating indicated by the spore and acritarch taxa corresponds only to the Frasnian age (table 6.1). This age corresponds to that of the brachiopods and corals in the same region.

6.2 LABORATORY PROCESSING

The samples were processed in the palynological laboratories of the Botany Department, University of Bristol, and National Iranian Oil Company, Tehran. A combination of standard processing procedures taken from several sources, notably Cross (1964) and Allen (1965), was adapted to suit the types of lithology and the time available.

Each palynological sample was washed in water to remove surface contamination. After drying, specimens were crushed to <5 mm in diameter between sheets of paper on an anvil, with both anvil and hammer being washed after every crushed sample. Twenty grams of each crushed sample was treated with hydrochloric (35.5%) and hydrofluoric (42%) acid, in order to remove carbonates and silicates respectively. The remainder was sieved through a 15 micron mesh screen to remove unwanted fine particles, mainly sapropel. The treatment was followed

Table 6.1 – Stratigraphic range-chart of acritarchs and spores from the Frasnian successions in Kerman.

Identification[1] of acritarch and spore taxa	Devonian						
	Early			Middle		Late	
	Loch[2]	Prag[2]	Ems[2]	Eif[2]	Giv[2]	Fras[2]	Fam[2]
Acritarchs							
Baltisphaeridium crassiechanatun						—	—
Chomotriletes bistchoensis						—	
Chomotriletes vedugensis						—	
Cymatiosphaera sp.	—	—	—	—	—	—	
Deltotosoma intonsum						—	
Gorgonisphaeridium abstrusum						—	
Leiosphaeridium sp.	—	—	—	—	—	—	
Lophosphaeridium segregum						—	
Michrystridium sellatum	—	—	—	—	—	—	—
Multiplicisphaeridium ramusculosum	—	—	—	—	—	—	
Papulogabata annulata						—	
Polyedryxium sp.	—	—	—	—	—	—	
Solisphaeridium spinoglobosum			—	—	—	—	
Stellinium sp.					—	—	
Unellium comptum					—	—	—
Veryhachium downiei	—	—	—	—	—	—	—
Veryhachium trispinosum	—	—	—	—	—	—	
Spores							
Acinosporites acanthomammillatus				—	—	—	
Ancyrospora carnavonensis						—	
Apiculatisporites adavalensis				—	—	—	
Calyptosporites sp.				—	—	—	
Geminospora lemurata						—	
Geminospora punctata					—	—	
Hystricosporites sp.				—	—	—	
Leiotriletes sp.	—	—	—	—	—	—	
Punctatisporites sp.	—	—	—	—	—	—	
Samarisporites triangulatus					—	—	
Retusotriletes distinctus				—	—	—	
Retusotriletes rotundus			—	—	—	—	—

[1]Sources for the above identifications and the biostratigraphic ranges of each taxon are: Allen (1965), Balme (1962, 1988), Ghavidel-Syooki (1989), Kimyai (1979), Loboziak and Streel (1980), McGregor (1981), Playford (1977), Playford and Dring (1981), Richardson (1965), Richardson and McGregor (1986), Skaya (1988) and Staplin (1961).

[2]Loch = Lochkovian, Prag = Pragian, Ems = Emsian, Eif = Eifelian, Giv = Givetian, Fras = Frasnian, Fam = Famennian.

by hot hydrochloric acid to remove silicate gel. The floras were separated from the residual by zinc bromide with specific gravity of 1.95-2.0. This stage of treatment resulted in separation of heavy minerals from organic residues. Microscope slides were prepared from the residue which contains humic matter, acritarchs, spores and other acid-resistant organic entities.

6.3 SAMPLES STUDIED

Twenty-four samples were treated. The results are given in table 6.2.

Table 6.2 – Results of the treated samples from the Devonian outcrops in Kerman.

Section	Number of Samples	
	Total	Productive
Gerik	2	1
Hutk	5	3
Nedenu	6	-
Shams Abad	4	3
Tizi	7	7
Total	24	14

As shown in table 6.2, the Nedenu section failed to produce palynomorphs, but all other sections contain some spores and acritarchs (see Figs. 6.1-6.4). The grey shales from the Tizi outcrop yielded the best preserved and most diverse spore and acritarch assemblages. Twenty-nine spore and acritarch taxa were determined, including 12 spores and 17 acritarchs. Determination of the spore and acritarch taxa was made by Dr. Ghavidel-Syooki (National Iranian Oil Company). Thanks are extended to him for his assistance.

No attempt has been made to analyse abundances of individual species and/or varieties within any of the samples because of the time limitation; however, further studies may provide more information for palaeoenvironmental analysis.

Slides are stored in the Palaeontological Department of the National Iranian Oil Company, Tehran, Iran.

The shale samples from four sections in northern Kerman mostly contain well-preserved and abundant spores, acritarchs and some scolecodonts (table 6.1 and Figs. 6.1-6.4), but the samples of the Nedenu section lack palynomorphs. The identified acritarch and spore taxa are: *Acinosporites acanthomammillatus, Ancyrospora carnavonensis, Apiculatisporites advanensis, Baltisphaeridium crassiechinatum, Calyptosporites* sp., *Chomotriletes vedugensis, Chomotriletes bistchoensis, Cymatiosphaera* sp., *Deltotosoma intonsum, Geminospora lemurata, Geminospora punctata, Gorgonisphaeridium abstrusum, Hystricosporites* sp., *Michrystridium sellatum, Multiplicisphaeridium ramusculosum, Lophosphaeridium segregum, Leiosphaeridium* sp., *Leiotriletes* sp., *Punctatisporites* sp., *polyedryxium* sp., *Samarisporites triangulatus, Papulogabata annulata, Retusotriletes distinctus, Retusotriletes rotundus, Solisphaeridium spinoglobosum, Stellinium* sp., *Unellium comptum, Veryhachium trispinosum,* and *Veryhachium downiei.* In terms of relative abundance, the dominant spore and acritarch species are: *Geminospora lemurata, Samarisporites triangularis, Chomotriletes vedugensis, Chomotriletes bistchoensis, Deltotosoma intonsum* and *Papulogabata annulata.* Based on the occurrence of diagnostic taxa, such as *Geminospora lemurata, Samarisporites triangulatus, Chomotriletes vedugensis, Chomotriletes bistchoensis, Deltotosoma intonsum* and *Papulogabata annulata,* the encountered assemblage of the Kerman region is considered to be Frasnian in age (table 6.1).

6.4 STRATIGRAPHICAL SIGNIFICANCE OF THE MICROFLORAS

Little is known about Devonian palynomorphs from Iran. Kimyai (1979) has described 25 spores and acritarchs from the Devonian formations of northern Iran. Three taxa including *Acinosporites* *acanthomammillatus*, *Samarisporites triangulatus* and *Veryhachium trispinosum* were also found in Kerman. Recent research by Ghavidel-Syooki (1989) has revealed 73 spore and acritarch taxa from the Devonian sediments in southeastern Iran. Eleven of those taxa, including *Chomotriletes vedugensis*, *Deltotosoma intonsum* and *Geminospora lemurata*, are also present within the shale beds in Kerman. Among these flora six taxa (e.g. *Chomotriletes bistchoensis)* have been referred to as Frasnian (Ghavidel-Syooki, 1989).

The assemblage from the Kerman region is thus considered to be Frasnian in age (table 6.1). Seven of the Kerman taxa have been recorded also from the Frasnian sediments in northern and southeastern Iran (Kimyai, 1979; Ghavidel-Syooki, 1989). Eight taxa of palynomorphs from the Kerman region were previously reported from Frasnian formations in Western Australia (Balme, 1962, 1988; Playford and Dring, 1981).

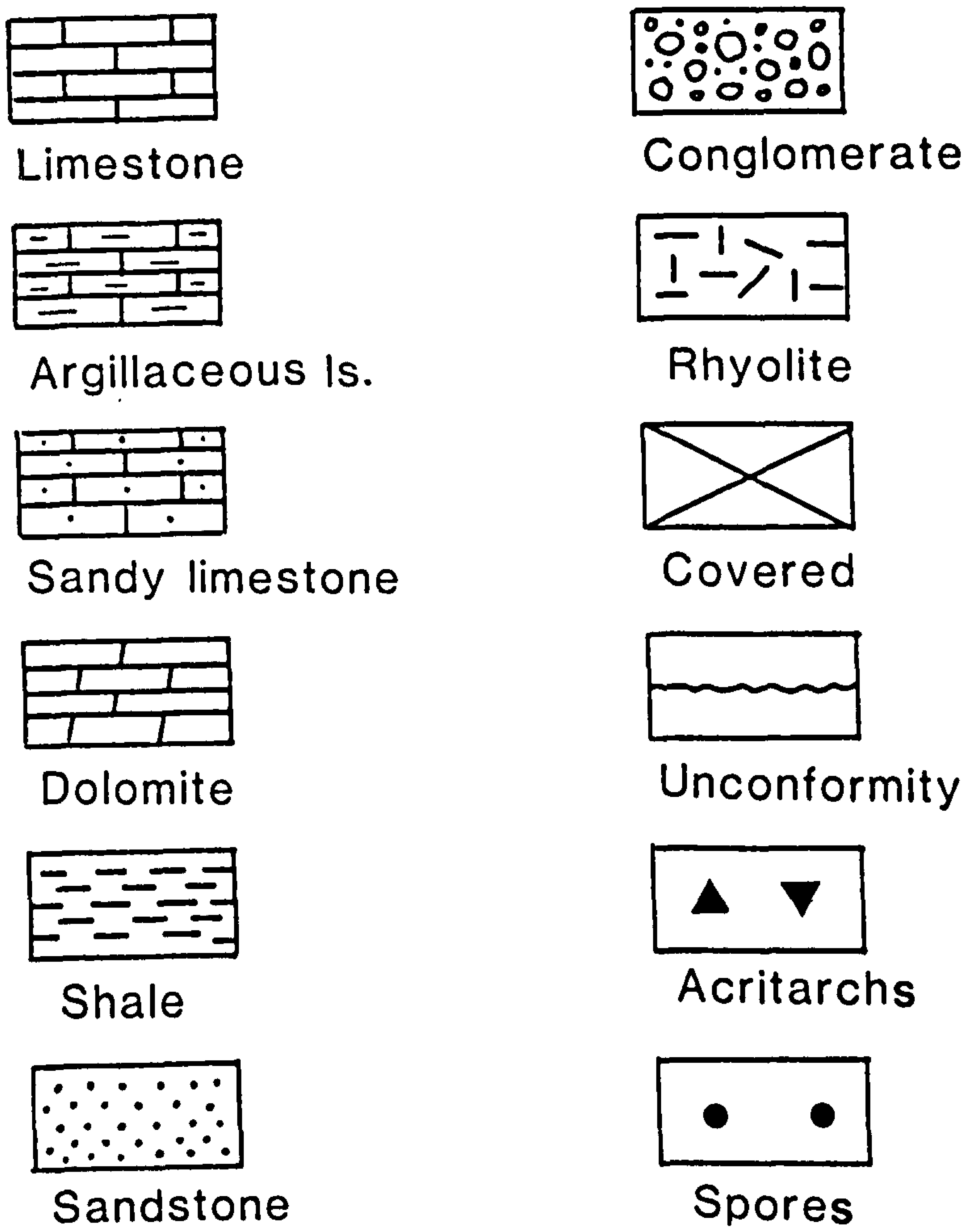
One of the most notable aspects of the Kerman assemblage is the occurrence of bifurcating spinous spores such as *Ancyrospora* and *Hystricosporites*. Species of these genera have been recorded from the Middle Devonian in northeast Scotland (Richardson, 1964) and in European USSR (McGregor, 1981). Some acritarch taxa, e.g. *Michrystridium sellatum* and *Leiosphaeridium* as applied herein and by other authors (Playford and Dring, 1981; Richardson, 1964), have a broad range from Early to Late Devonian. Nevertheless, the numerous (9 taxa) distinctively Frasnian index floras clearly indicate a Frasnian age in Kerman (see table 6.1 and Figs. 6.1-6.4). Thus, it must be assumed that bifurcate spinous spores are confined to the Upper Devonian in this area.

As Loboziak and Streel (1980) have suggested, species (shown in table 6.1) with a narrow vertical range in the stratigraphic successions may well be useful for correlation. Ghavidel-Syooki (1989) has shown that the palynomorphs from the Faraghan Formation, southeastern Iran, are identical to those of the Arabian Peninsula and Western Australia. As pointed out above, many spores and acritarchs (11 taxa) from the Kerman area have also been recorded from southeastern Iran. The similarity of the Kerman assemblages to those of southern Iran, Western Australia and Saudi Arabia indicates that these areas were in the same biogeographic province in Frasnian time.

The presence of marine fossils, including brachiopods and acritarchs with abundant microspores, in the Tizi area indicates a shallow marine environment of deposition.

The brachiopods and corals from the Gerik, Hutk and Shams Abad sections confirm the Frasnian age proposed from spore and acritarch taxa (see Figs. 3.2, 3.3 and 3.5 for details about brachiopods and corals).

Explanation of the symbols used in figures 6.1–6.4.



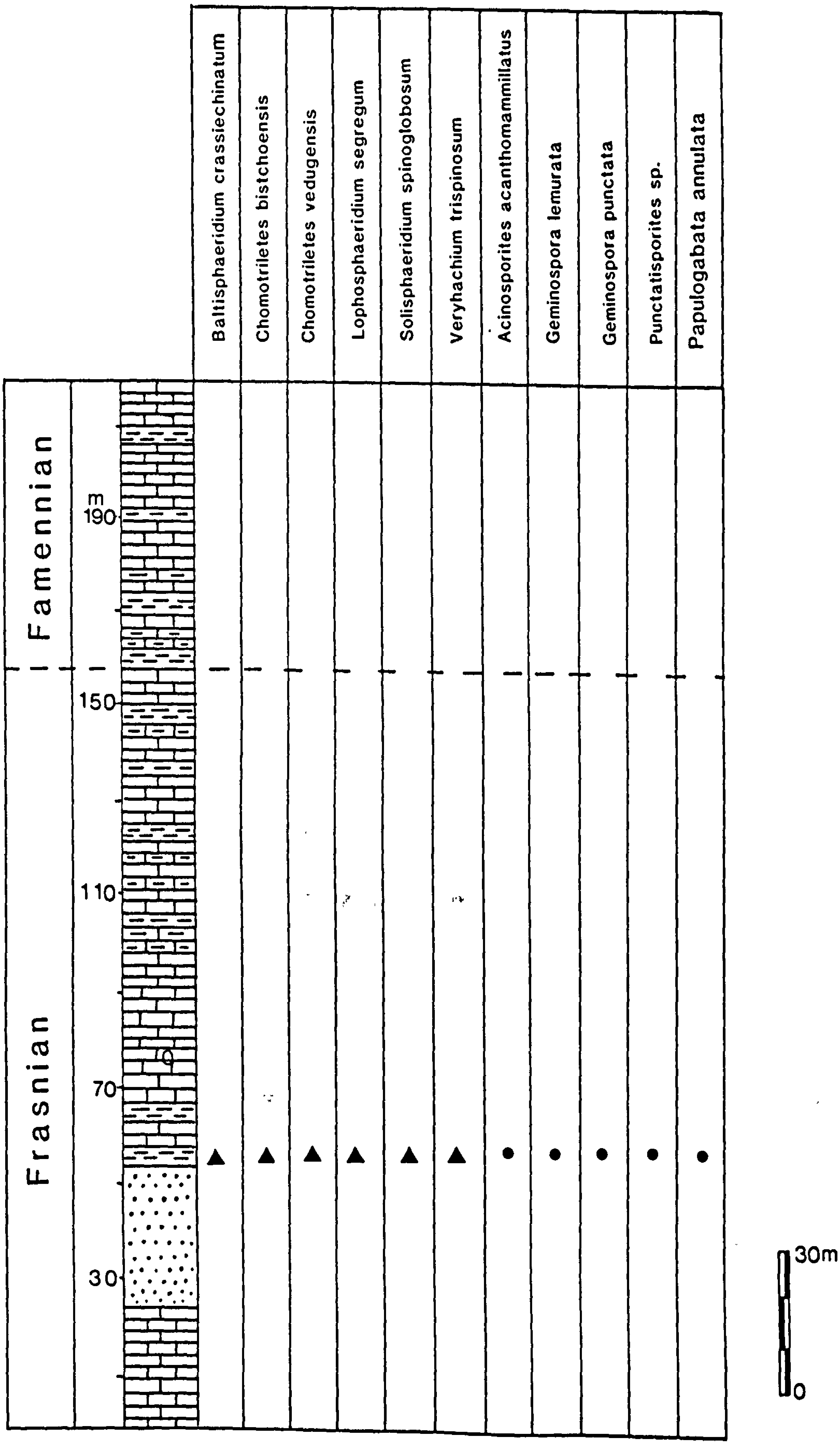


Fig. 6.1– Stratigraphical sequence of acritarchs and spores in the Gerik section.

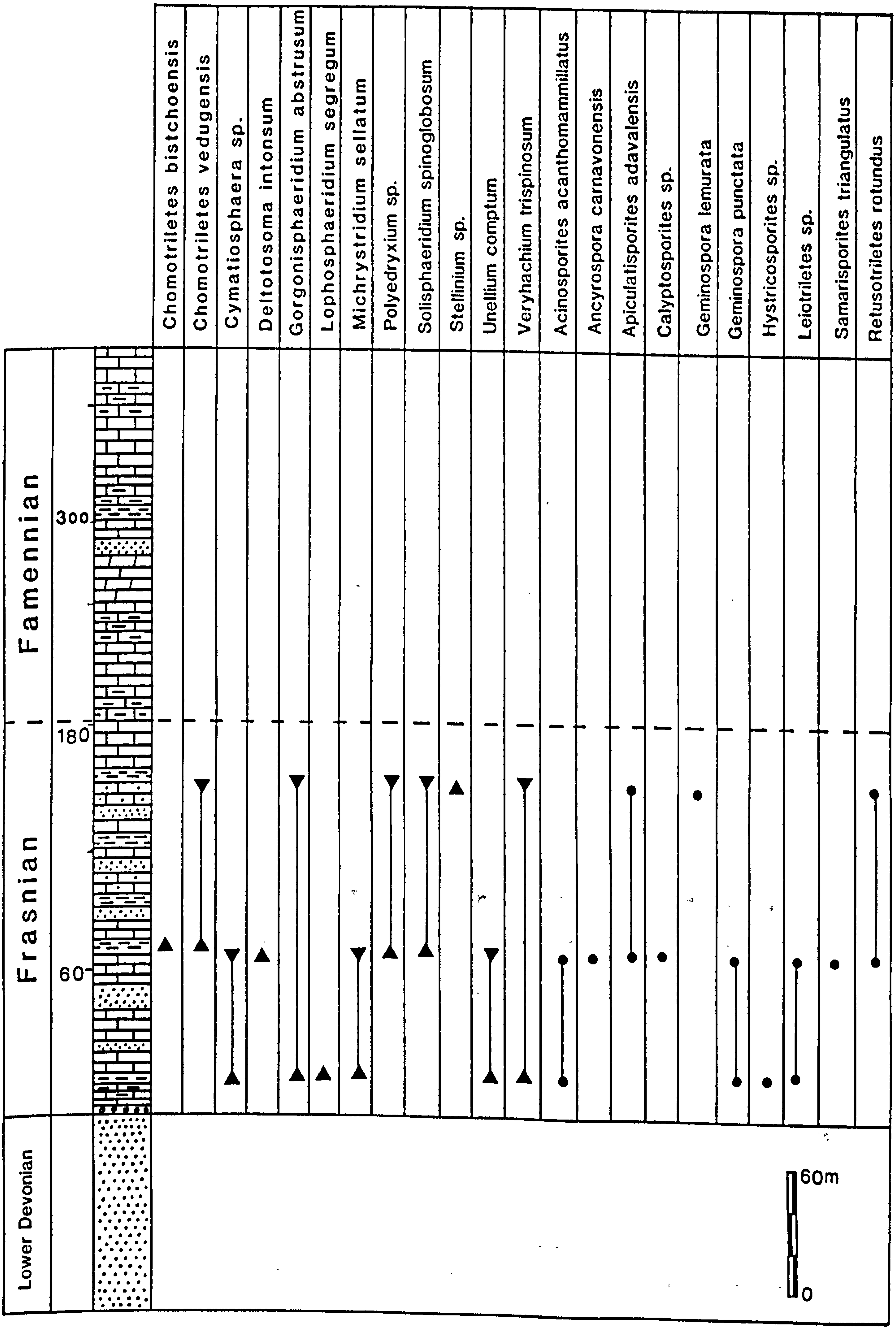


Fig. 6.2- Stratigraphical sequence of acritarchs and spores in the Hutk section.

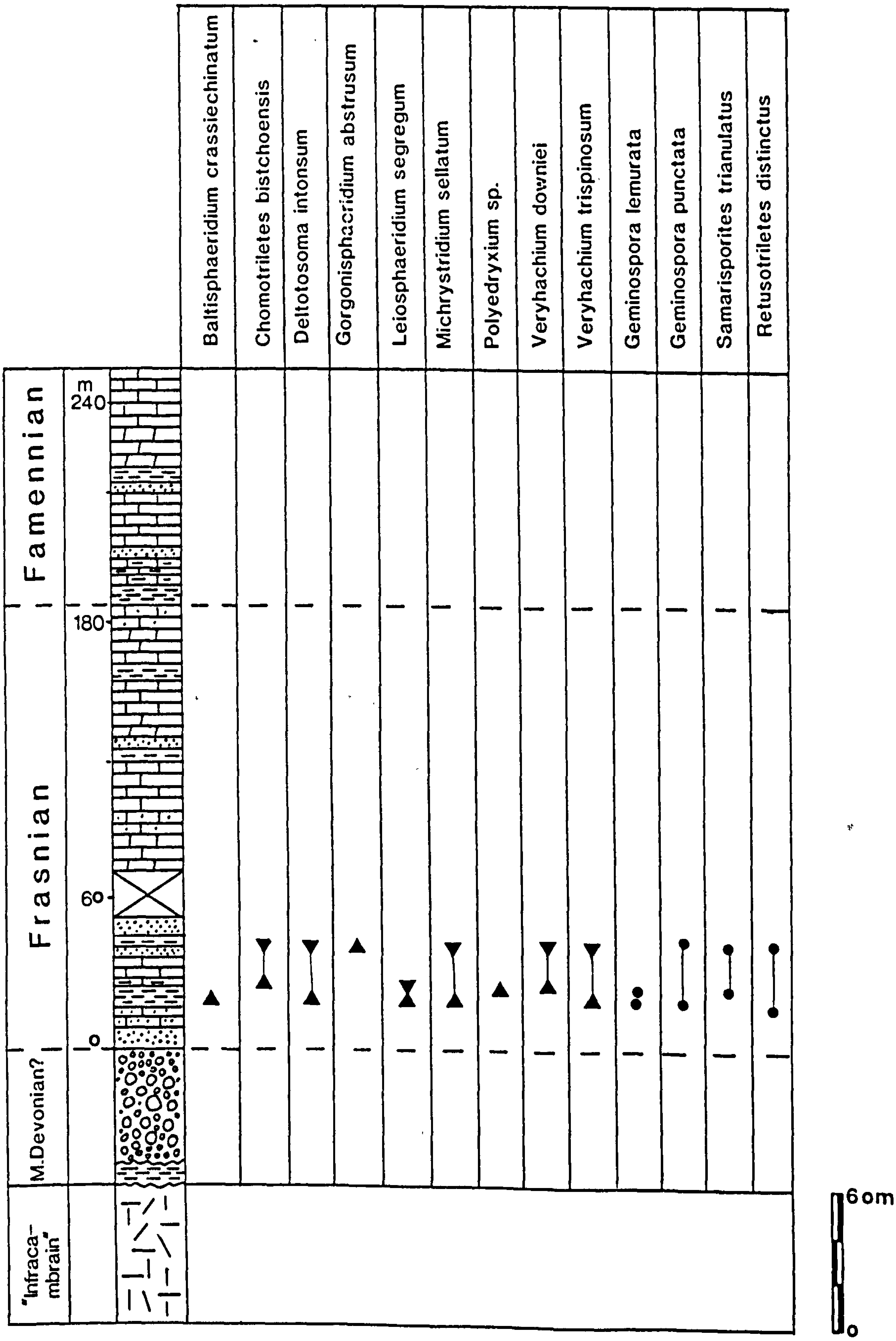


Fig. 6.3- Stratigraphical sequence of acritarchs and spores in the Shams Abad section.

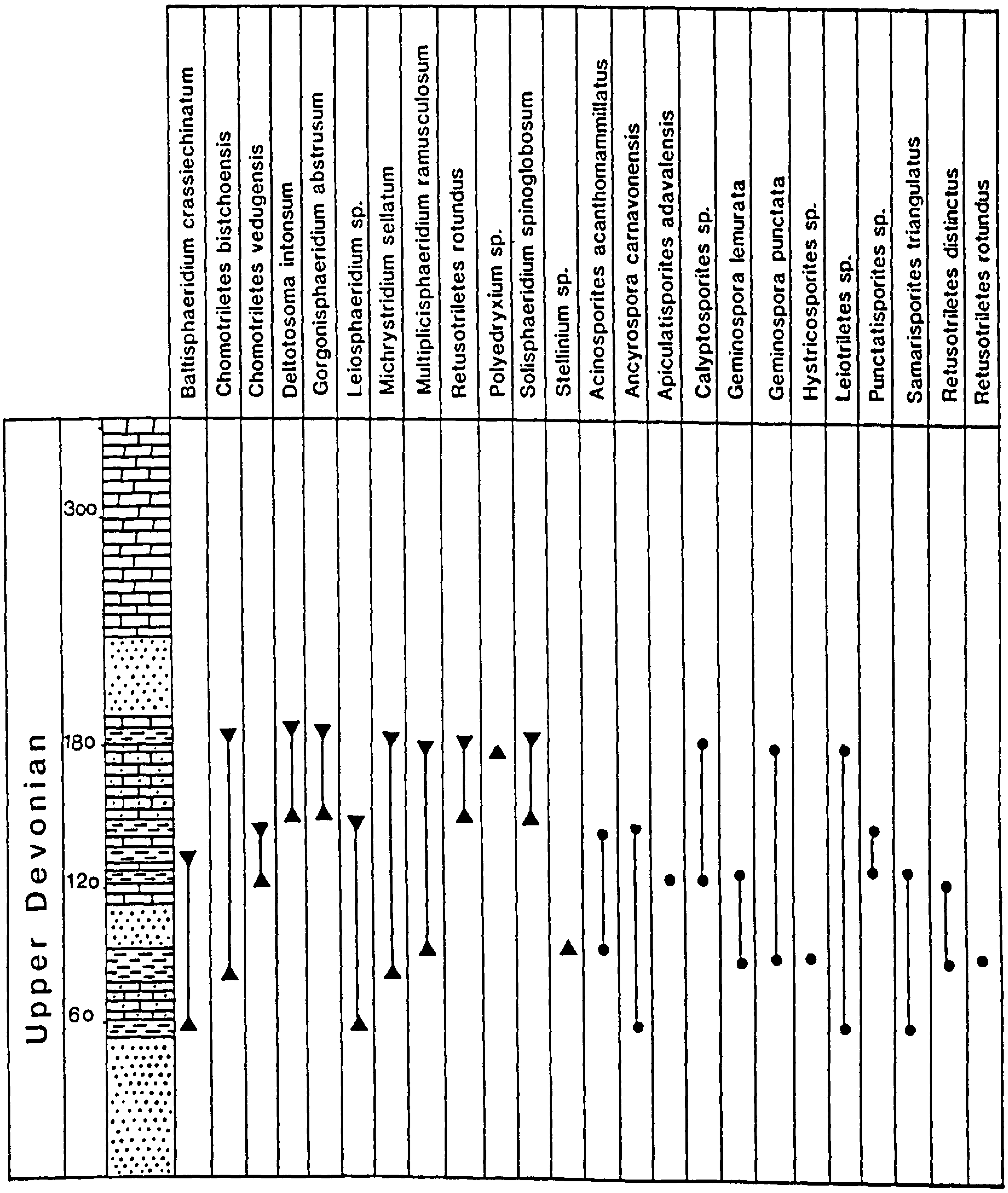


Fig. 6.4- Stratigraphical sequence of acritarchs and spores in the Tizi section.

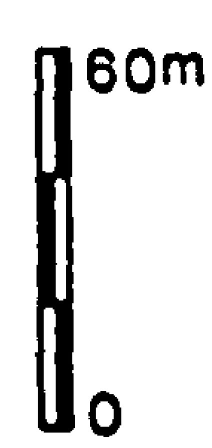


Plate 6.1

(All figures ×600)

Fig. 1. *Acinosporites acanthomammillatus* Richardson, 1965, Hutk section, levels 20 m and 70 m, sample MD18.

Fig. 2. *Ancyrospora carnavonensis* (Balme), Brideaux and Radforth, 1970, Tizi section, levels 80 m and 185 m, sample TS8.

Fig. 3. *Ancyrospora carnavonensis* (Balme), Brideaux and Radforth, 1970, Hutk section, level 70 m, sample MD18. TS8.

Fig. 4. *Samarisporites triangulatus* Allen, 1965, Tizi section, level 85 m, sample TS10.

Fig. 5. *Hystricosporites* sp., Hutk section, level 20 m, sample MD17.

Fig. 6. Broken processes of *Ancyrospora*, Tizi section, level 80 m, sample TS8.

Fig. 7. *Geminospora lemurata* Balme, 1962, Shams Abad section, level 20 m, sample MD45.

Fig. 8. *Calyptosporites* sp., Tizi section, level 185 m, sample TS14.

Fig. 9. Broken processes of *Ancyrospora*, Hutk section, level 70 m, sample MD18.

Fig. 10. *Geminospora lemurata* Balme, 1962, Tizi section, level 130 m, sample TS12.

Fig. 11. *Densosporites* sp., Tizi section, level 60 m, sample TS8.

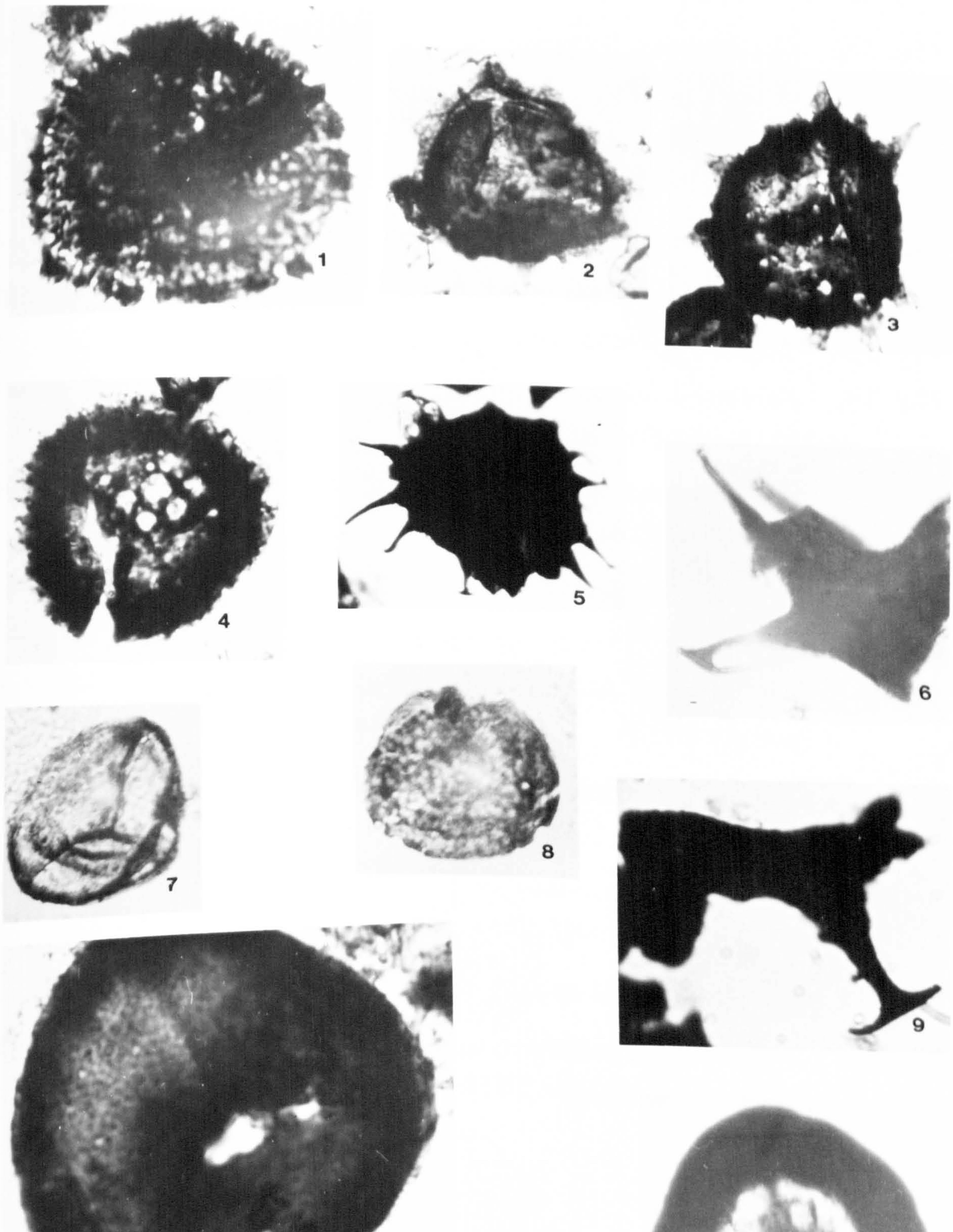

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Plate 6.2

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Fig. 12. *Densosporites* sp., Tizi section, level 60 m, sample TS8.

Fig. 13. *Geminospora lemurata* Balme, 1962, Hutk section, level 70 m, sample MD18.

Fig. 14. *Geminospora punctata* Owens, 1971, Tizi section, level 140 m, sample TS13.

Fig. 15. *Punctatisporites* sp., Tizi section, level 130 m, sample TS12.

Fig. 16. *Geminospora lemurata* Balme, 1962, Shams Abad section, level 20 m, sample MD45.

Fig. 17. *Retusotriletes rotundus*, Streel Streel, 1967, Tizi section, level 85 m, sample TS10.

Fig. 18. *Retusotriletes distinctus* Richardson, 1965, Shams Abad section, level 20 m, sample MD45.

Fig. 19. *Geminospora lemurata* Balme, 1962, Gerik section, level 45 m, sample MD26.

Fig. 20. *Geminospora lemurata* Balme, 1962, Hutk section, level 70 m, sample MD18.

Fig. 21. *Geminospora lemurata* Balme, 1962, Tizi section, level 80 m, sample TS9.

Fig. 22. *Apiculatisporis adavalensis* De Jersey, 1966, Tizi section, level 130 m, sample TS12.

Fig. 23. *Punctatisporites* sp., Tizi section, level 140 m, sample TS13.

Fig. 24. *Acinosporites acanthommilatus* Richardson, 1965, Tizi section, level 140 m, sample TS13.

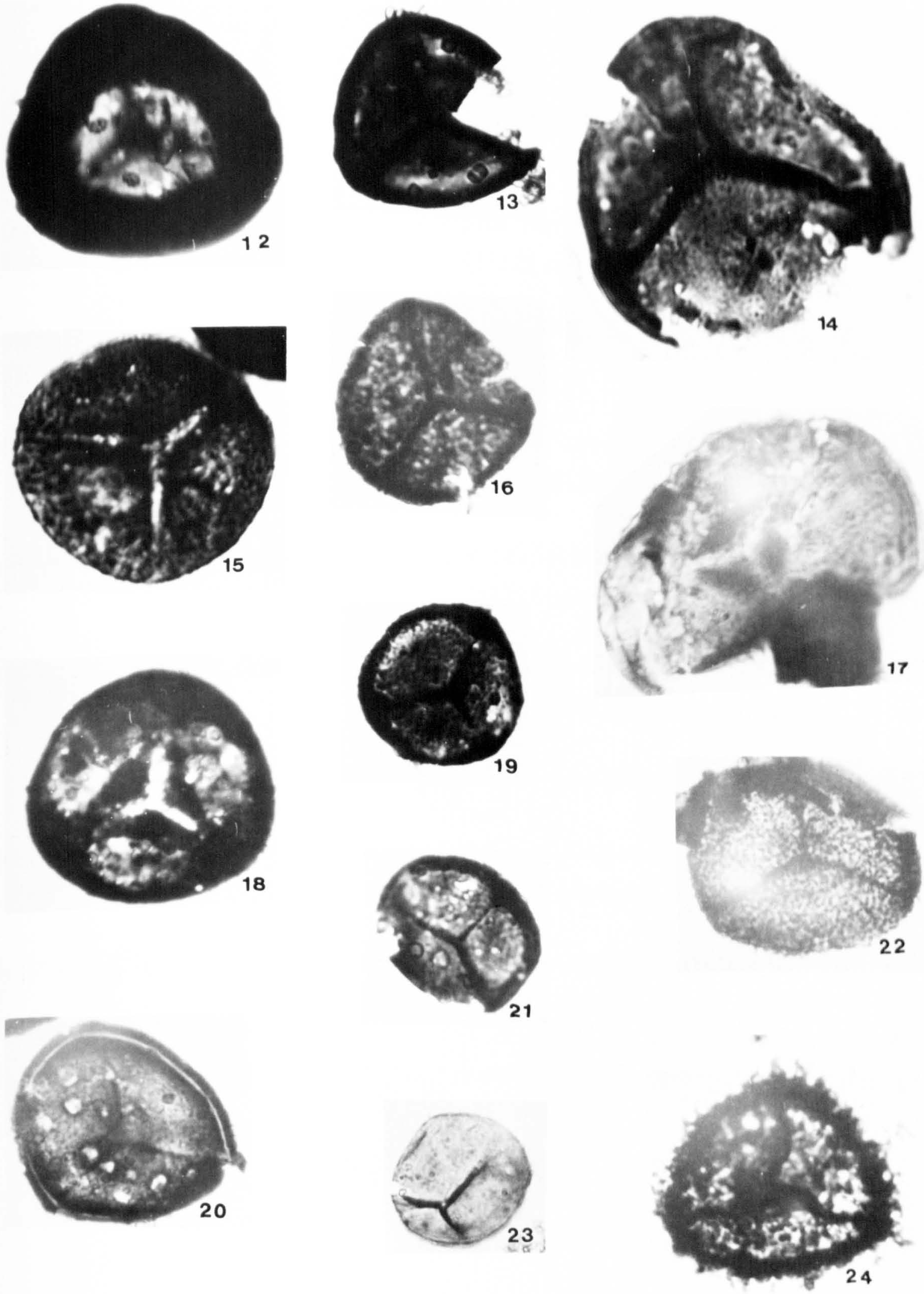
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Plate 6.3

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Fig. 25. *Deltotosoma intonsum* Playford, 1981, Hutk section, level 160 m, sample MD24.

Fig. 26. *Deltotosoma intonsum* Playford, 1981, Tizi section, level 130 m, sample TS12.

Fig. 27. *Gorgonisphaeridium abstrusum* Playford, 1981, Hutk section, level 70 m, sample MD18.

Fig. 28. *Chomotriletes bistchoensis* Staplin, 1961, Shams Abad section, level 50 m, sample MD48.

Fig. 29. *Chomotriletes vedugensis* Naumova, 1953, Gerik section, level 45 m, sample MD26.

Fig. 30. *Chomotriletes bistchoensis* Staplin, 1961, Shams Abad section, level 20 m, sample MD45.

Fig. 31. *Chomotriletes vedugensis* Naumova, 1953, Tizi section, level 125 m, sample TS11.

Fig. 32. *Leiosphaeridia* sp., Tizi section, level 60 m, sample TS8.

Fig. 33. *Gorgonisphaeridium abstrusum* Playford, 1981, Hutk section, level 70 m, sample MD18.

Fig. 34. *Solisphaeridium spinoglobosum* (Staplin, 1961), Wicander, 1974, Gerik section, level 45 m, Section MD26.

Fig. 35. *Scolecodont*, Tizi section, level 125 m, sample TS11.

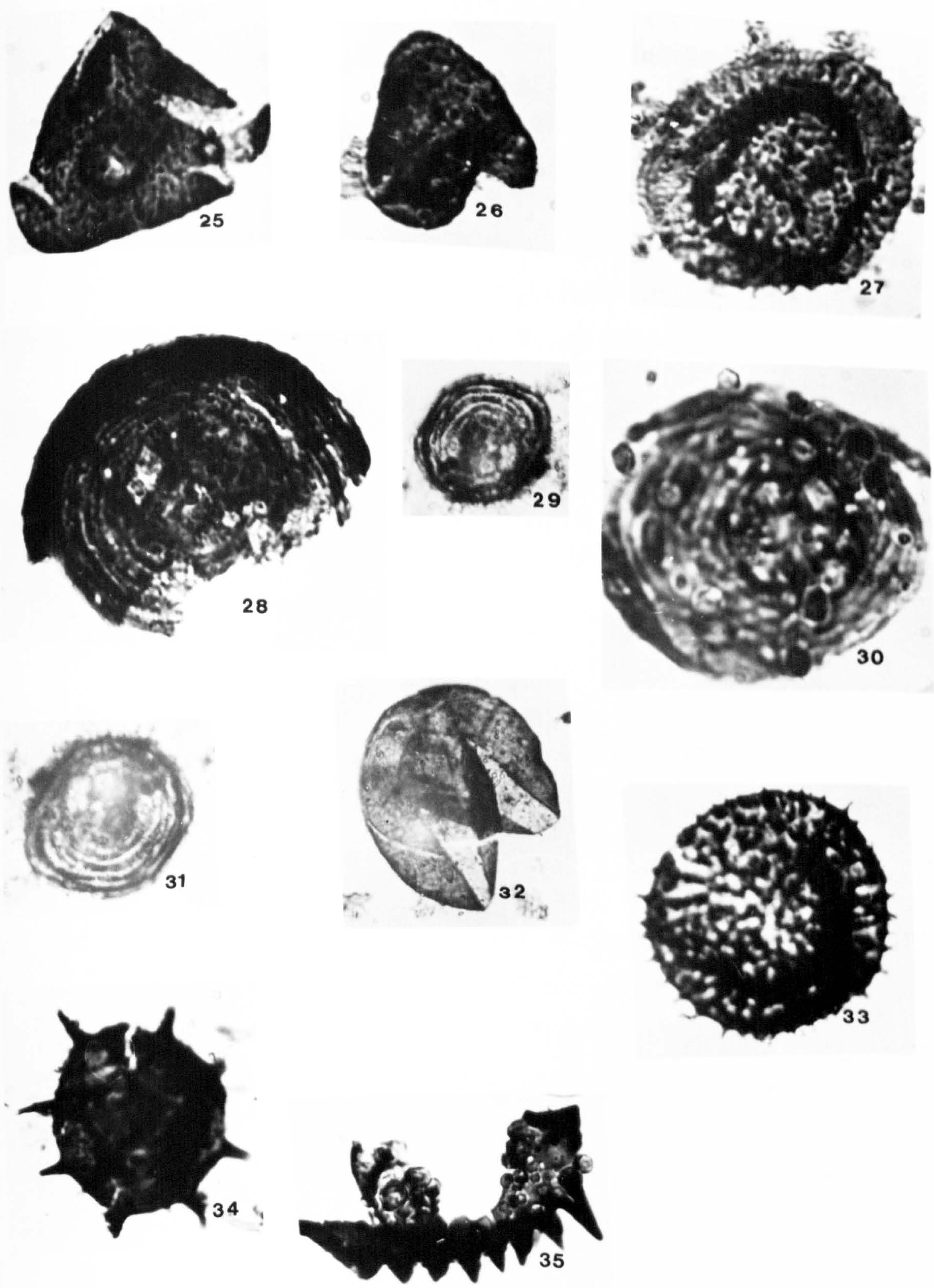
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Plate 6.4

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Fig. 37. *Veryhachium downiei* Stockmans and Williere, 1962, Shams Abad section, level 20 m, sample MD45.

Fig. 38. *Veryhachium* sp., Hutk section, level 150 m, sample MD24.

Fig. 39. *Veryhachium trispinosum* Stockmans and Williere, 1962, Hutk section, level 160 m, sample MD24.

Fig. 40. *Veryhachium trispinosum* Cramer, 1971, Shams Abad section, level 50 m, sample MD48.

Fig. 41. *Veryhachium* sp., Shams Abad section, level 50 m, sample MD48.

Fig. 42. *Veryhachium trispinosum* Cramer, 1971, Gerik section, level 45 m, sample MD26.

Fig. 43. *Veryhachium trispinosum* Cramer, 1971, Hutk section, level 70 m, sample MD18.

Fig. 44. *Veryhachium* sp., Gerik section, level 45 m, sample MD26.

Fig. 45. *Michrystridium* sp., Tizi section, level 80 m, sample TS9.

Fig. 46. *Veryhachium trispinosum* Cramer, 1971, Shams Abad section, level 50 m, sample MD48.

Fig. 47. *Veryhachium trispinosum* Cramer, 1971, Hutk section, level 20 m, sample MD17.

Fig. 48. *Lophosphaeridium segregum* Playford, 1981, Hutk section, level 20 m, sample MD17.

Fig. 49. *Solisphaeridium spinoglobosum* Wicander, 1974, Tizi section, level 140 m, sample TS13.

Fig. 50. *Solisphaeridium* sp., Tizi section, level 130 m, sample TS12.

Fig. 51. *Solisphaeridium* sp., Tizi section, level 130 m, sample TS12.

Fig. 52. *Stellinium* sp., Hutk section, level 160 m, sample MD24.

Fig. 53. *Cymatiosphaera* sp., Hutk section, level 20 m, sample MD17.

Fig. 54. *Unellium comptum* Wicander and Wood, 1981, Hutk section, level 20 m, sample MD17.

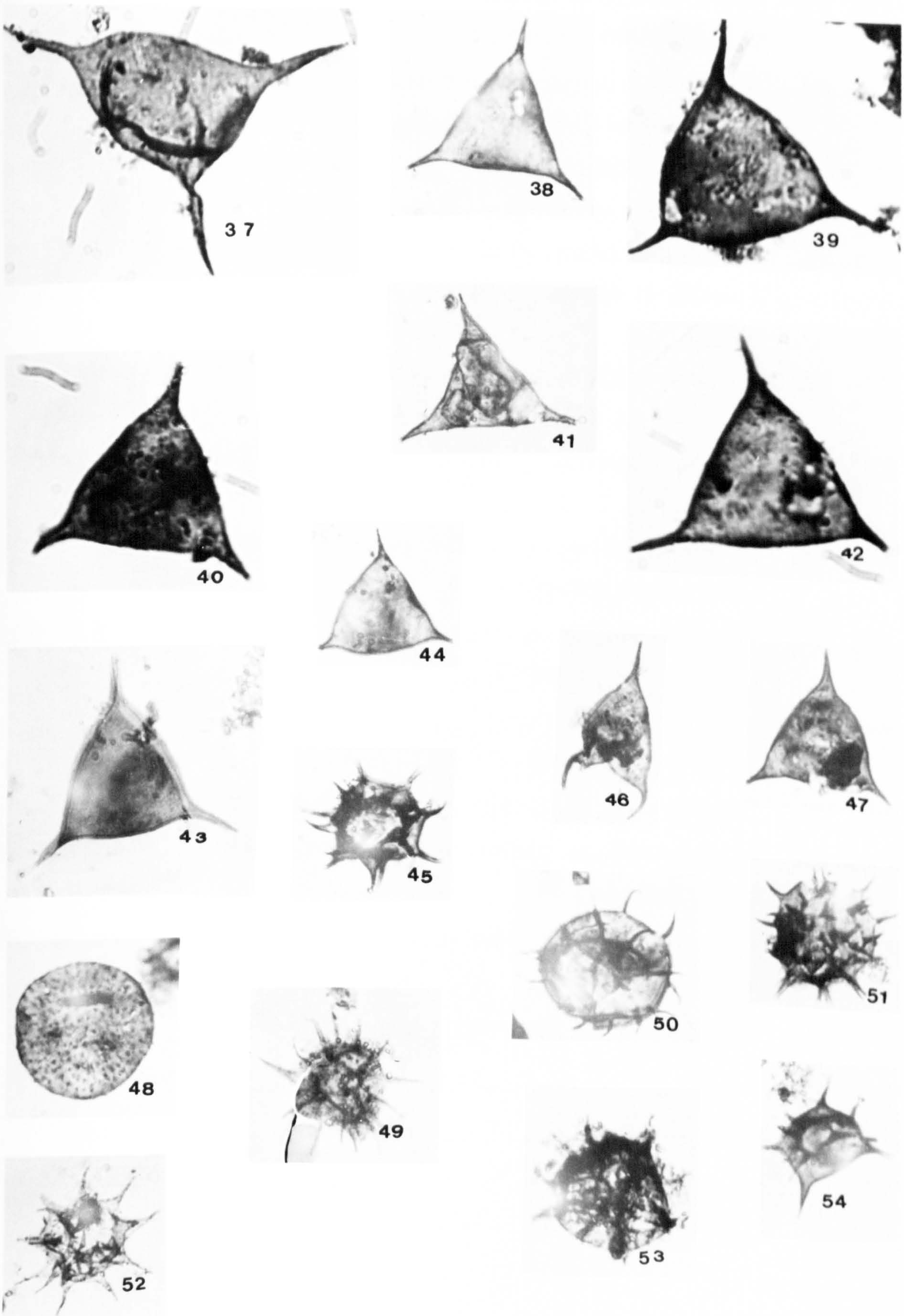
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Fig. 55. *Multiplicisphaeridium ramusculosum* Denuff, 1955, Tizi section, level 80 m, sample TS9.

Fig. 56. *Baltisphaeridium crassiechinatum* (Staplin, 1961), Downie et al., 1963, Gerik section, level 26 m, sample MD45.

Fig. 57. *Solisphaeridium spinoglobosum* Wicander, 1974, Hutk section, level 70 m, sample MD18.

Fig. 58. *Baltisphaeridium crassiechinatum* (Staplin, 1961), Downie et al., 1963, Shams Abad section, level 20 m, sample MD45.

Fig. 59. *Solisphaeridium spinoglobosum* Wicander, 1974, Hutk section, level 160 m, sample MD24.

Fig. 60. *Lophosphaeridium* sp., Gerik section, level 45 m, sample MD26.

Fig. 61. *Solisphaeridium spinoglobosum* Wicander, 1974, Tizi section, level 125 m, sample TS11.

Fig. 62. *Solisphaeridium spinoglobosum* Wicander, 1974, Tizi section, level 185 m, sample TS14.

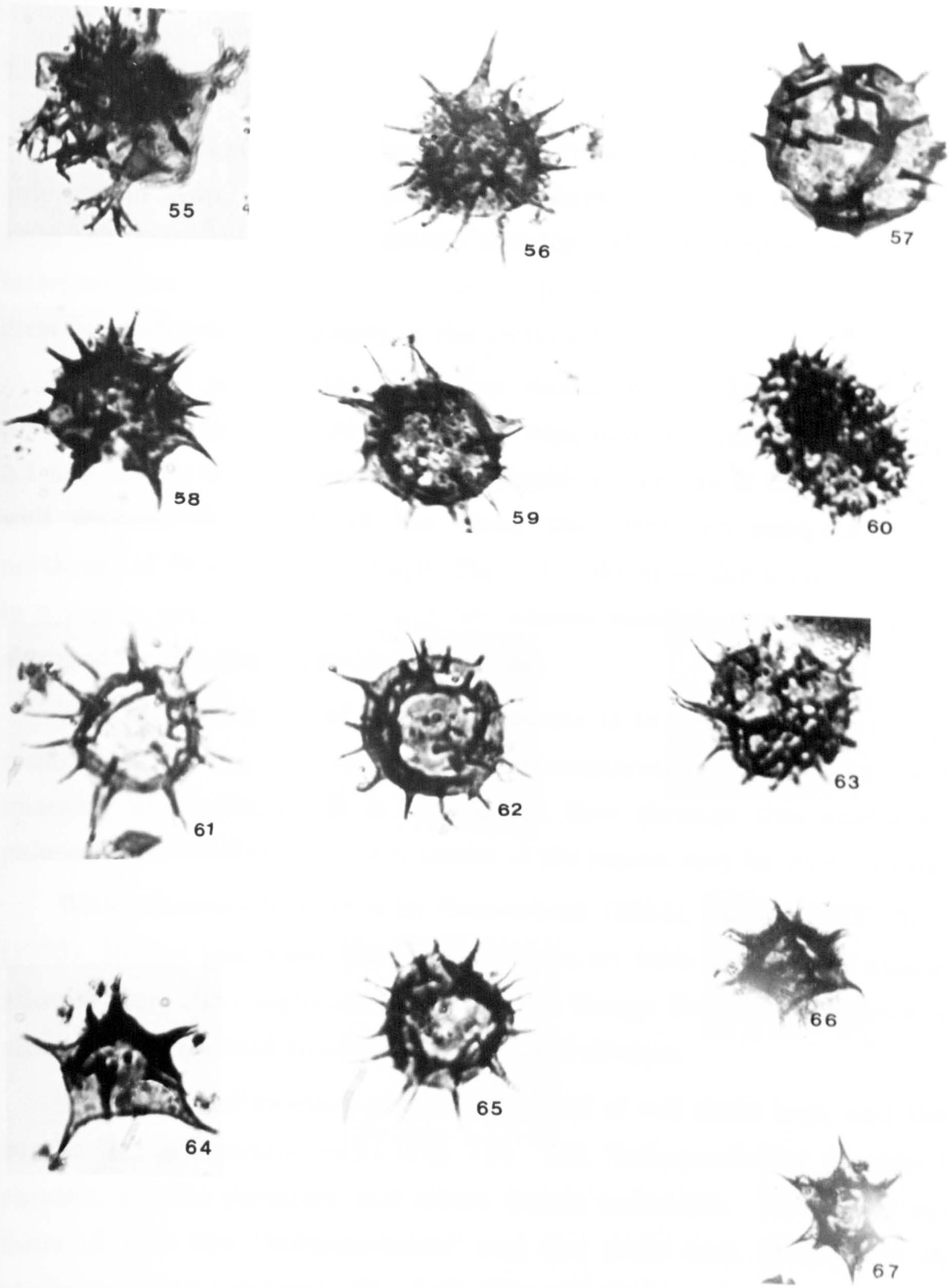
Fig. 63. *Baltisphaeridium crassiechinatum* (Staplin, 1961), Downie et al., 1963, Tizi section, level 130 m, sample TS12.

Fig. 64. *Unellium* sp., Hutk section, level 20 m, sample MD17.

Fig. 65. *Michrystridium stellatum* Deflandre, 1945, Tizi section, level 80 m, sample TS9.

Fig. 66. *Polyedryxium* sp., Shams Abad section, level 20 m, sample MD45.

Fig. 67. *Michrystridium* sp., Hutk section, level 70 m, sample MD18.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CHAPTER 7

AN ALLUVIAL FAN DEPOSIT IN ZANGU MOUNTAIN

7.1 INTRODUCTION

Conglomerates have been reported from most of the Devonian outcrops in Iran. Their genetic sedimentary processes are important since they possibly indicate tectonic activity. They also provide data for interpretation of palaeoenvironment, palaeoclimate, palaeotransport direction and palaeogeography of the Devonian in Iran.

The basal unit of the Devonian strata in the Zangu Mountain, northwest Kerman, is a 20–56 m thick conglomerate unit. (See Figures 3.1 and 3.5 for the location and stratigraphical position of this unit.) It is well exposed for about 12 km along the Devonian outcrop to the northeast of Shams Abad village (Fig. 7.1). Because the area is located in a region with dry climate and low annual rainfall, the rocks are not obscured by soil and vegetation (Fig. 7.2a).

This detailed study of the conglomerate is to determine the overall configuration of the unit, the source of the material and the regional sedimentary environment. It is also hoped that through this analysis a palaeoclimatic and sedimentary model of the region may be constructed.

With reference to studies by Blissenbach (1954), Hooke (1967), Miall (1970), Nemec and Steel (1984) and others on both recent and ancient alluvial fans, the conglomerate unit in the Zangu Mountain suggests an alluvial fan deposited in an arid to semiarid climate.

The basal sedimentary unit is composed of red shale beds and they overlie "Infracambrian" rocks (Fig. 7.3). The "Infracambrian" consists of rhyolite, granite porphyry and minor clastic sediments. The upper surfaces of both the "Infracambrian" and the shale unit throughout the study area are erosional (Fig. 7.4). The red shale beds are thinly laminated and extremely fissile but commonly contain clasts of the underlying rocks.

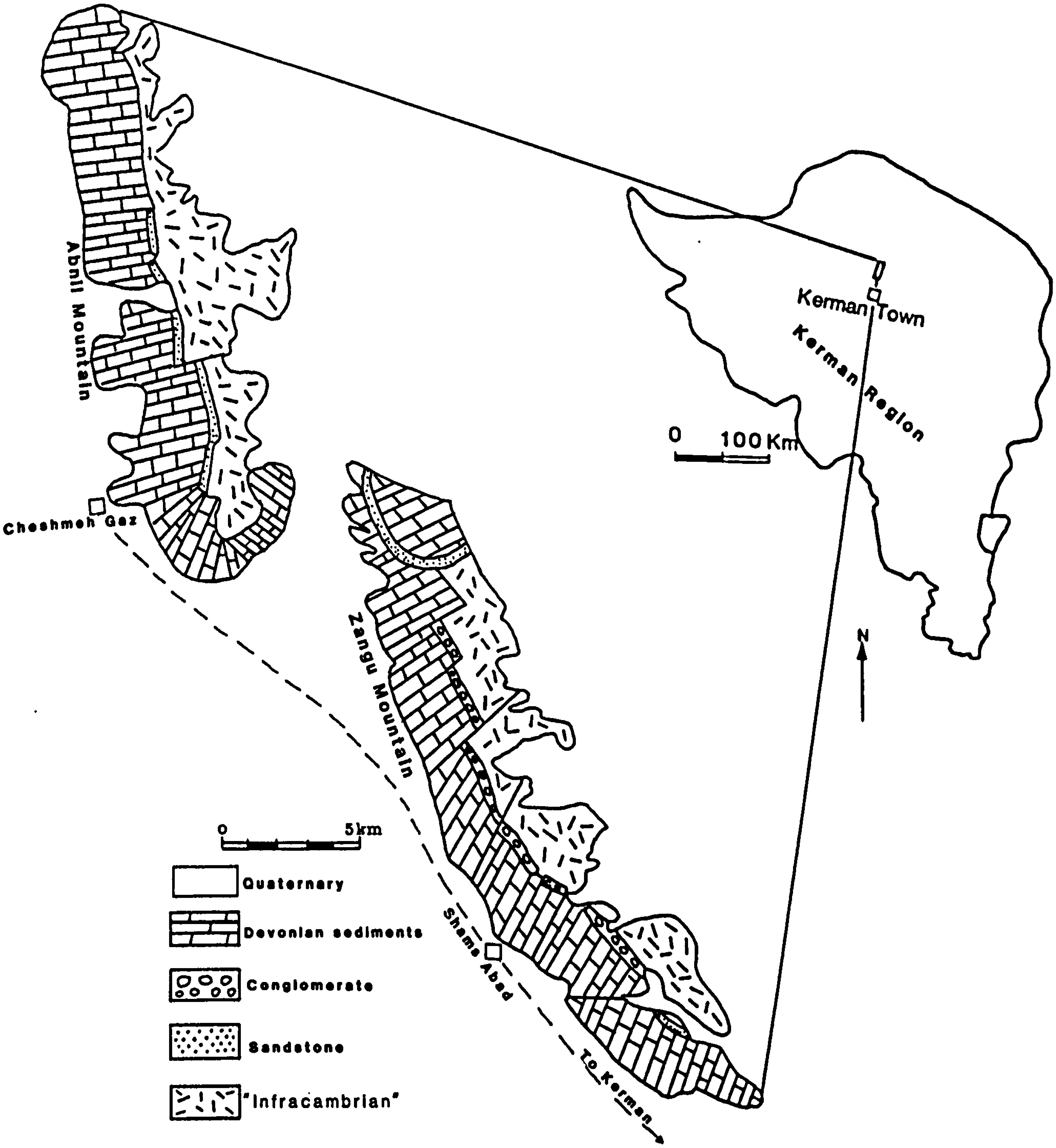
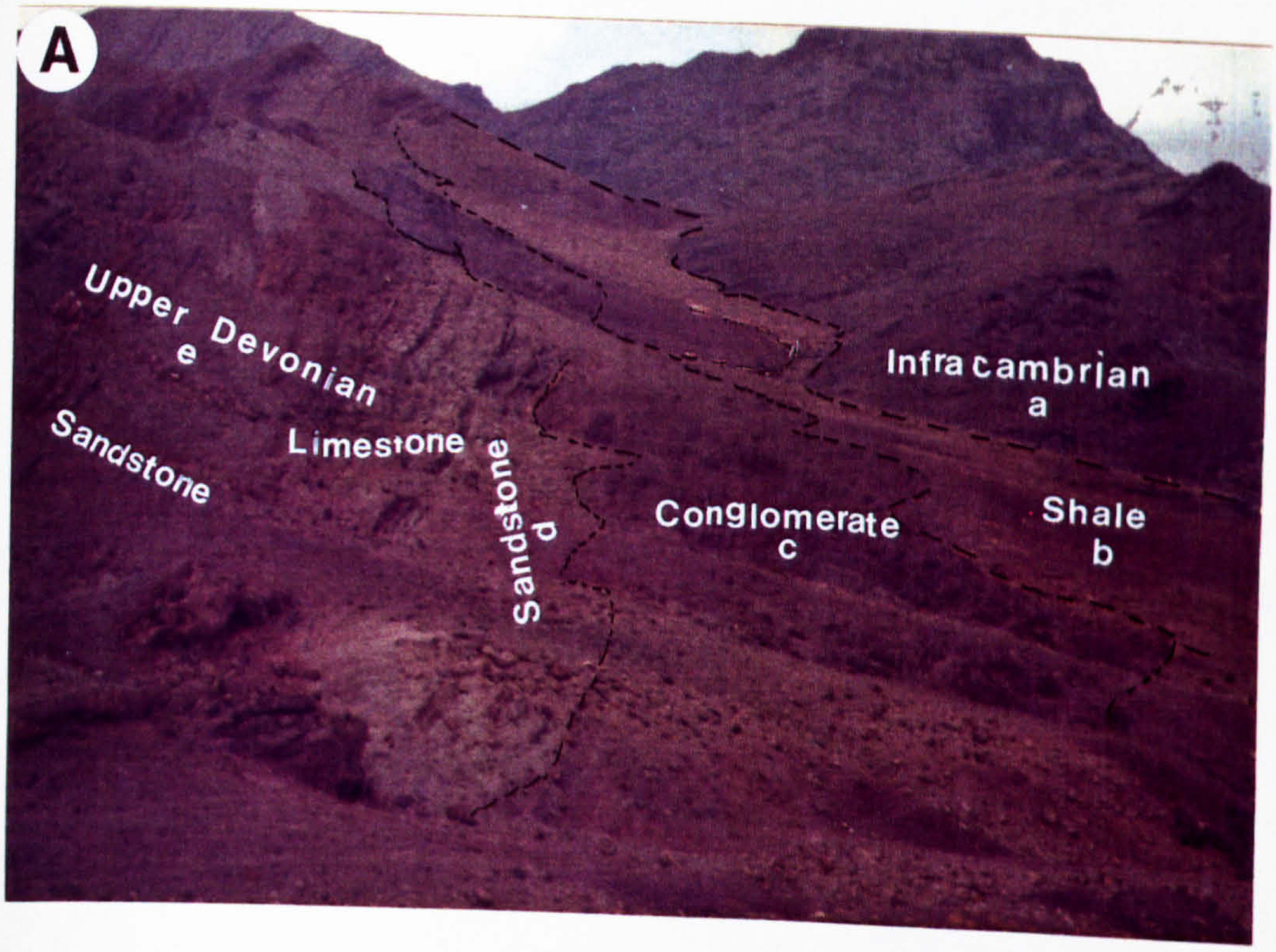


Figure 7-1–Location of the study area and map of the conglomerate outcrop in the Zangu Mountain.

Fig. 7.2 (A): Conglomerate outcrop and its relation with underlying and overlying rocks. Viewpoint on the east side of the section, about 50 m above the top of the conglomerate, 1500 m northeast of Shams Abad.

Fig. 7.2 (B): Conglomerate unit showing oriented clasts. Reddish brown clasts are rhyolite and white clasts are granite from underlying rocks. Location: Station 8, about 20 m above the base of the unit.


A
Upper Devonian
e
Sandstone
Limestone
Sandstone
d
Infracambrian
a
Conglomerate
c
Shale
b


B

Figure 7.3 – Generalised geological section, northwest Kerman (after Dimitrijevic, 1973).

Age	Unit	Thickness (m)	Lithology
?Early Carboniferous to Late ?Silurian	Kereshk Group		Limestone
		430	Limestone Ls. breccia Sandy limestone
		6-30	Sandstone
		20-56	Conglomerate
		10-20	Red shale
"Infra-cambrian"	Risu Series	441	Rhyolite, granite, microconglomerate, calcareous arenite and quartz breccia

The lower contact of the conglomerate unit is an unconformity (Fig. 7.4). Some pebble-sized mud balls of the underlying shale form approximately 5-7% of the basal part of the conglomerate, suggesting that the upper part of the shale eroded prior to the conglomerate deposition. The surface of the conglomerate with the overlying sandstone is typically planar and sharp, but in some places it appears gradational. The sandstone unit ranges in thickness from 6 to 30 m (Fig. 7.5).

The conglomerate is made of clasts up to -9ϕ (50 cm) with an average mean grain size between -4.14ϕ and -5.37ϕ. The clasts are mainly cobbles, pebbles and sand size grains of quartzite, granite, rhyolite, chert and mudballs with rare boulders and blocks of the underlying rocks. The proportions of these clasts in the total assemblage of the conglomerate

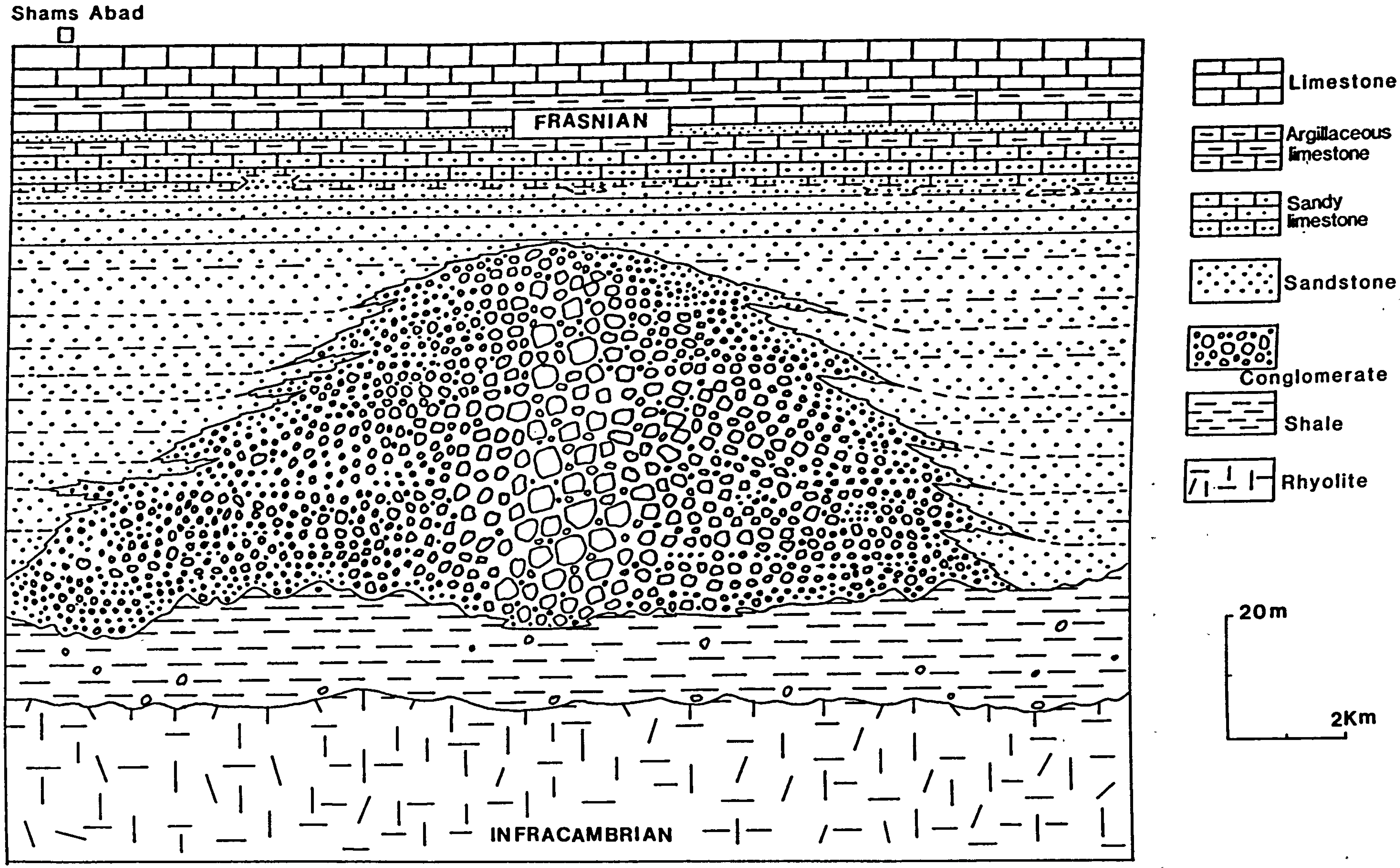


Figure7.4-Generalized cross-section through the Zangu Mountain,showing relationship between the conglomerate and it's adjacent rocks.

volume are: (1) boulders and blocks, 5–7%; (2) cobbles, 20–25%; (3) pebbles, 35–40%; (4) sand, 15–20%. This assemblage changes relative to the mean grain size particles. The cement comprises about 15–20% of the volume of the conglomerate.

Fossils have not been found in this unit. Sedimentary structures are absent except for some clast imbrication (Fig. 7.2b). The conglomerate unit reveals thick to very thick beds with interbedded sandstone lenses. Individual beds are commonly wedge-shaped with irregular bedding surfaces.

The sandstone above the conglomerate contains rare large (sinuous-lonate) ripples and hummocky trough cross-bedding (Fig. 7.5).

The map by Dimitrijevic (1973) shows the conglomerate extending northward about 14 km to the Abnil Mountain north of Cheshmeh Gas Village, but it was not confirmed during the present study. The unit extends for about 7 km northwards from east of Shams Abad where it grades to sandstone in the northern part of the Zangu Mountain and in the Abnil Mountain (Fig. 7.1).

Dimitrijevic (1973) assigned a ?Late Silurian to ?Early Carboniferous age to the rocks in the northeast Shams Abad, called the "Kereshk Group" (see Fig. 7.3). Brachiopods, corals, spores and acritarchs indicate a Late Devonian age for the succession above the conglomerate. It should be mentioned that the microconglomerate unit of the Hutk area is local and not related to the Zangu conglomerate.

7.2 LITHOLOGY

The conglomerate is of relatively uniform composition and generally red brown in colour. Fortunately nearly all the clasts within the unit are distinctive and identifiable in hand specimen.

Particles larger than -3ϕ (8 mm) are referred to as clasts and smaller particles are collectively termed the matrix. The size of the particles ranges from cobble to silt. The texture shows clasts supported with sand and silt grains. The sand and silt matrix is 15% to 20% of the rock volume. There is little discernible change in matrix through the section, but grain size decreases distally from the center of the outcrop.

The composition of the conglomerate matrix reveals the following average percentages: quartz, 40; feldspar, 10; carbonate detrital grains, 23; chert and clay materials, 17; and weathered grains (originally ferromagnesian), 10. According to Folk (1974), this composition falls within the range of a lithic greywacke.

The mean particle size of the Zangu conglomerate matrix is about 0.7 mm with an arkosic composition. The matrix of recent alluvial fan deposits commonly is arkosic or greywacke (Blissenbach, 1954; Miall, 1970).

The cement comprises 15 to 20 percent of the conglomerate volume, and is siliceous material containing about 30% iron oxide.

The composition of the material is close to that of the underlying parent rocks. Syngenetic alteration had little influence on the composition of the deposits, suggesting that both the distance of transport and the time duration which the detritus was in contact with water was short. A lack of alteration products suggests minimal chemical weathering and hence an origin in semi-arid or arid climate.

7.3 GRAIN SIZE DISTRIBUTION

Conglomerates are commonly described in terms of grain size distribution. This characteristic can be found either through sieving of loose or disaggregated material or by field studies of grain size. The sieving technique cannot be applied to well cemented conglomerates, since some of the friable clasts will be broken on disaggregation. On the other hand, a cobble or boulder conglomerate requires very large samples for analysis to be statistically valid.

Several strategies for measurement of grain size in conglomerate may be used. Some workers prefer to measure only the largest clasts, e.g. measuring all clasts larger than 10 mm. Lindholm (1987) suggested that measurement of all large clasts which cross a transect of 0.5–5 m length depending on the clast size is adequate. Miall (1970), in the study of Devonian alluvial fans, considered only the grain size fraction larger than -3ϕ (8 mm). In the present study, distribution of clasts larger than -3ϕ (8 mm) in size was determined in the field by measuring all clasts present in an area of about 80×80 cm at every site and grouping the grain sizes into phi classes on the basis of their mean diameters. Miall (1970) suggested that measurement of a hundred clasts is necessary for consistent results, but in most cases apparent long diameters of about 400 clasts per station were determined with the aid of a ruler and/or a vernier caliper. This measurement was made at 12 stations (see Fig. 7.6 for locations).

Although sedimentologists agree on the application of the terms for various size of sedimentary particles, the definitions used for the boundary size are not uniform. Following most workers' preference, the Udden-Wentworth scale has been used in this study.

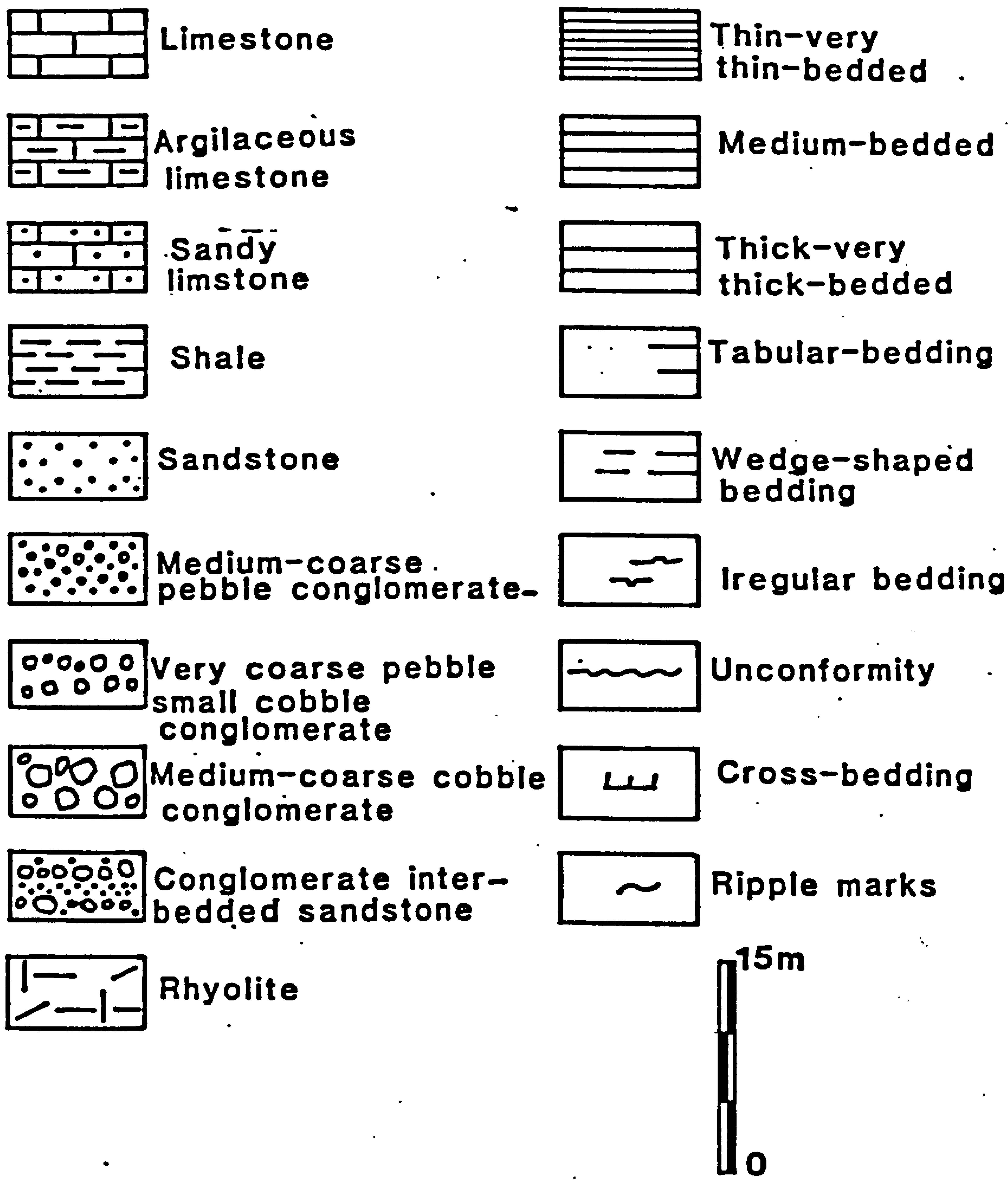
There are several methods of presenting grain size data, viz the cumulative frequency curve, histogram and frequency curve. The first is usually preferred. Grain size distribution was plotted against cumulative number percent rather than weight percent. This procedure is more adequate than the weight frequency (Swan et al., 1978).

Mean grain size and standard deviation were calculated in terms of

$$\bar{x} = \frac{\sum f\, m_\phi}{n} \quad \text{and} \quad \sigma = \sqrt{\frac{\sum f\,(m_\phi - \bar{x})}{n-1}}$$

$\bar{x}$	is the mean
f	is the frequency in number
m_ϕ	is the mid-point of each class interval in phi
n	is the total grain number ($\sum f$)
σ	is the standard deviation

A computer program was used for the statistical calculations. The results of grain size measurements and calculations are summarized in tables 7.1 and 7.2. The cumulative curves (Fig. 7.7) with the histograms (Fig. 7.8) all indicate almost unimodal size distribution. The overall configurations of the grain size cumulative curves are very similar in



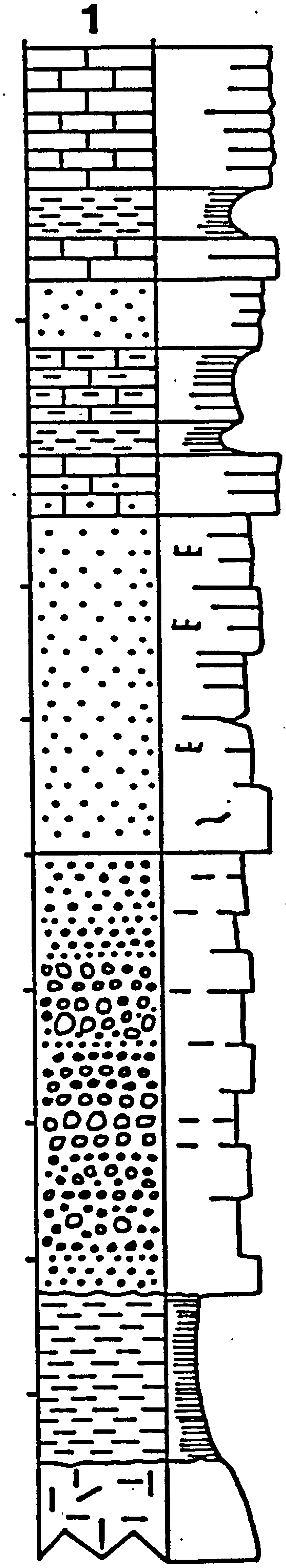
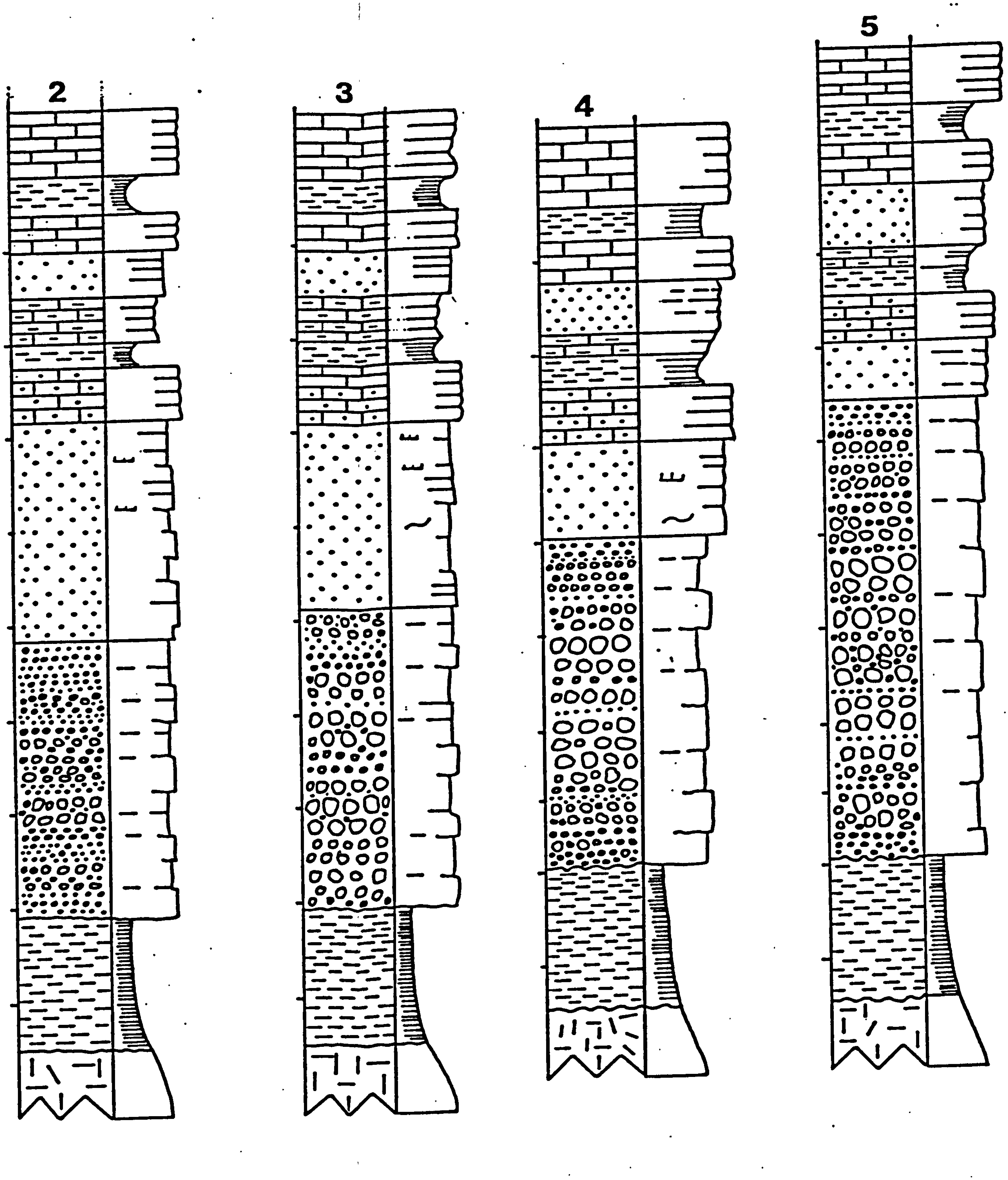


Figure 7:5- Measured sections through the conglomerate outcrop, showing lithology, thickness, clast size and sedimentary structures.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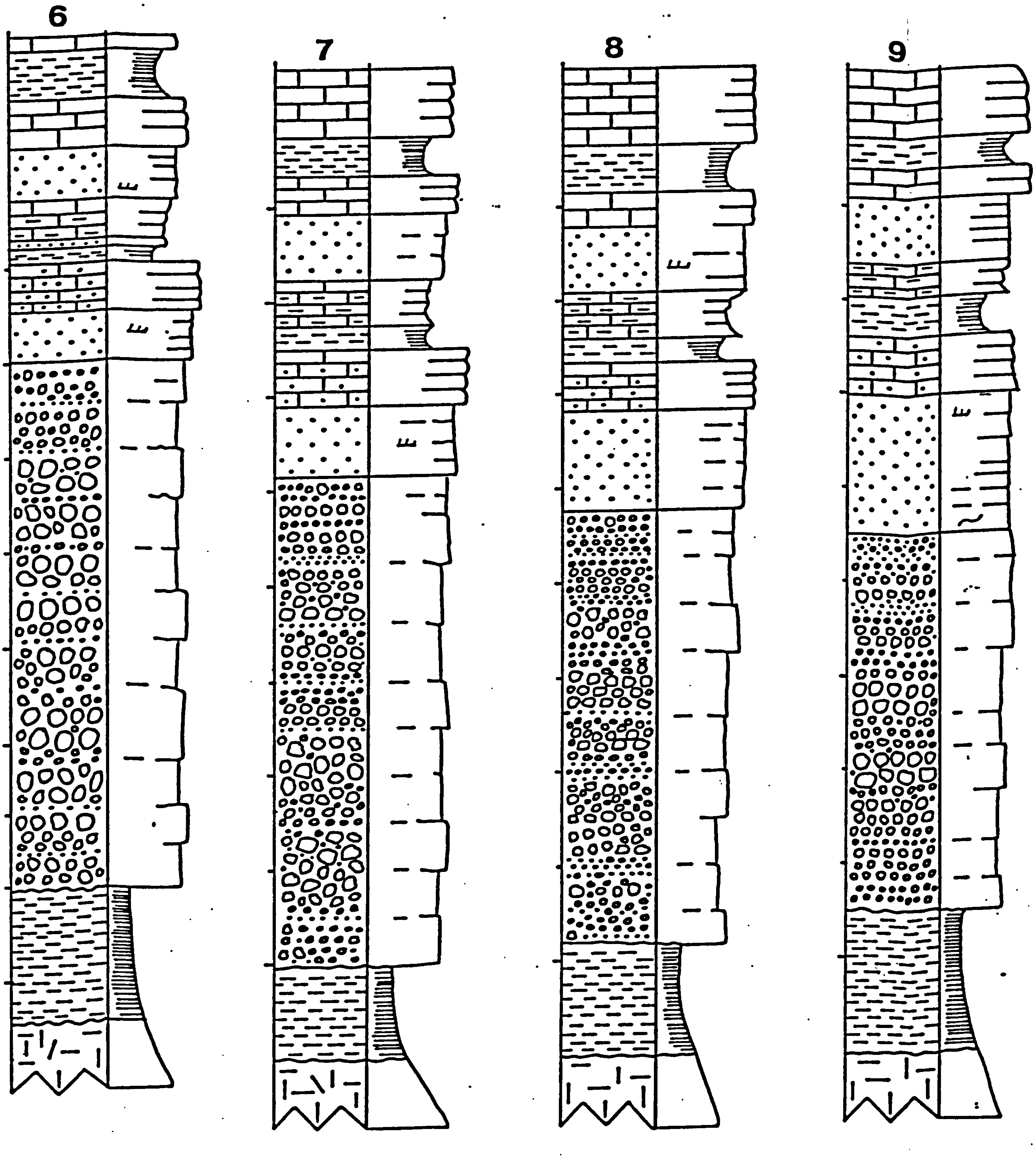
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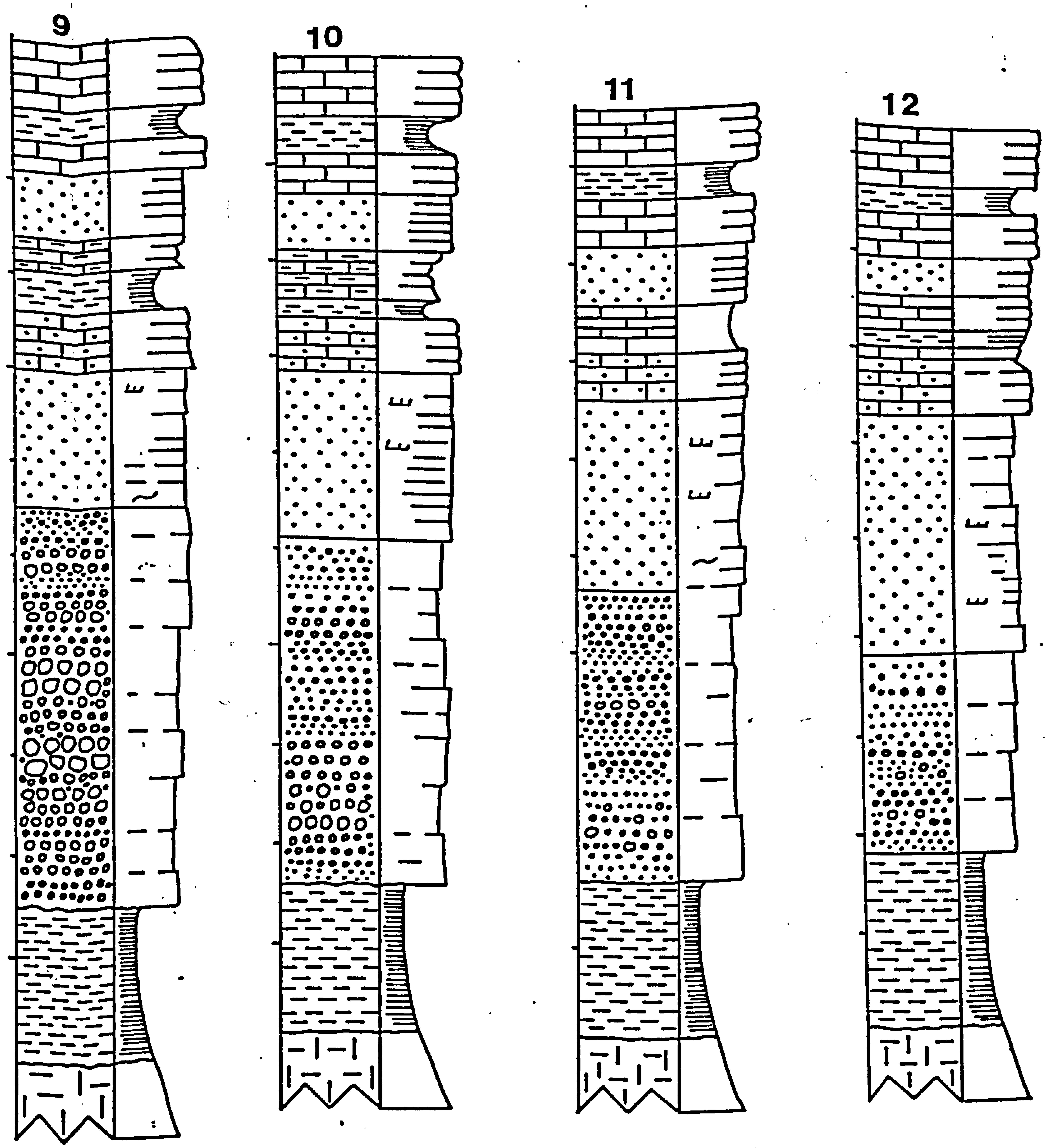
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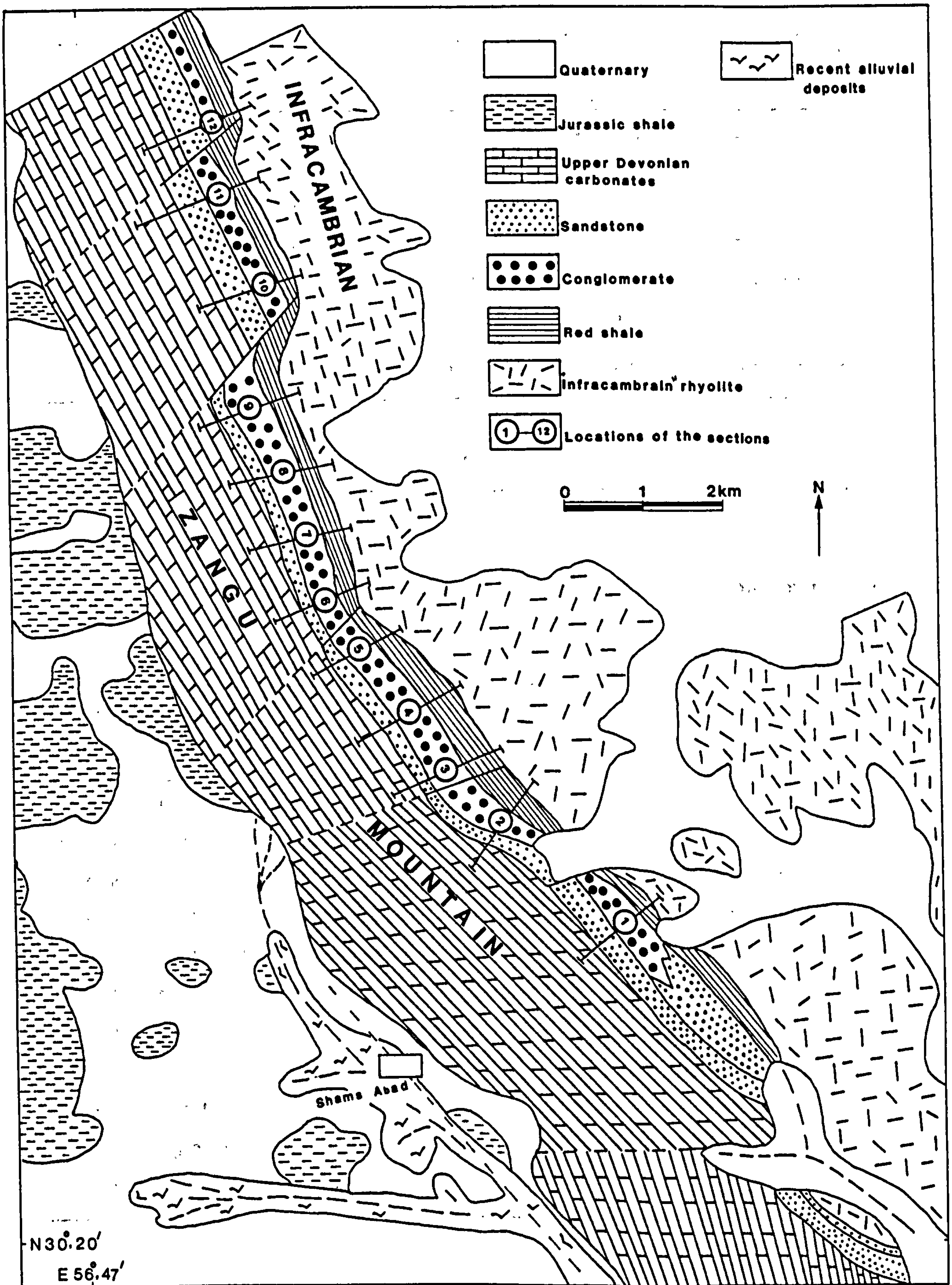


Fig. 7.6 -Geological map of the Zangu Mountain,northwest Kerman.

Table 7.1: The grain size measurements for 12 stations in the Zangu Mountain.

mm	mid-point ϕ	1	2	3	4	5	6	7	8	9	10	11	12
512-256	-8.5	2	2	2	4	8	16	6	4	2	-	-	-
256-128	-7.5	6	6	2	5	16	38	25	6	6	6	-	-
128-64	-6.5	28	25	32	32	26	60	45	34	30	8	4	2
64-32	-5.5	50	70	80	80	100	70	90	80	80	70	50	40
32-16	-4.5	66	60	80	85	60	75	60	74	68	80	105	90
16-8	-3.5	225	215	230	210	200	140	115	210	232	250	266	318
Total		378	377	426	416	410	399	341	408	418	414	425	450
Thickness		33	30	32	35	45	56	52	48	40	35	30	20
Max (cm)		25	23	27	30	40	42	40	30	26	22	15	10

Table 7.2: Results of statistical computer analysis for the grain size distribution.

Calc. Value	1	2	3	4	5	6	7	8	9	10	11	12
Mean	4.50	4.56	4.58	4.66	4.87	5.37	5.23	4.68	4.59	4.39	4.26	4.14
St. Dev.	1.09	1.10	1.05	1.12	1.65	2.18	1.35	1.15	4.10	0.92	0.73	0.66
Kur.	4.32	3.82	3.54	3.84	1.19	0.51	2.44	3.63	3.59	4.57	4.28	5.64
Skew.	1.37	1.18	1.05	1.10	0.62	0.33	0.53	1.07	1.10	1.33	1.20	1.53
95%	6.80	6.78	6.72	6.81	7.60	7.94	7.77	6.84	6.78	5.95	5.82	5.74
85%	5.75	5.80	5.79	5.84	5.92	6.91	6.73	5.86	5.81	5.62	4.93	4.83
75%	4.93	5.56	5.55	5.60	5.73	6.61	5.94	5.63	5.58	4.87	4.75	4.60
50%	3.91	3.93	3.96	3.99	4.54	4.84	4.96	3.98	3.95	3.91	3.89	3.85
25%	3.70	3.71	3.73	3.74	3.75	3.85	3.87	3.74	3.72	3.70	3.69	3.67
16%	3.63	3.64	3.64	3.66	3.72	3.72	3.73	3.65	3.64	3.63	3.62	3.61
0.5%	3.54	3.54	3.54	3.55	3.57	3.57	3.57	3.54	3.54	3.54	3.53	3.53

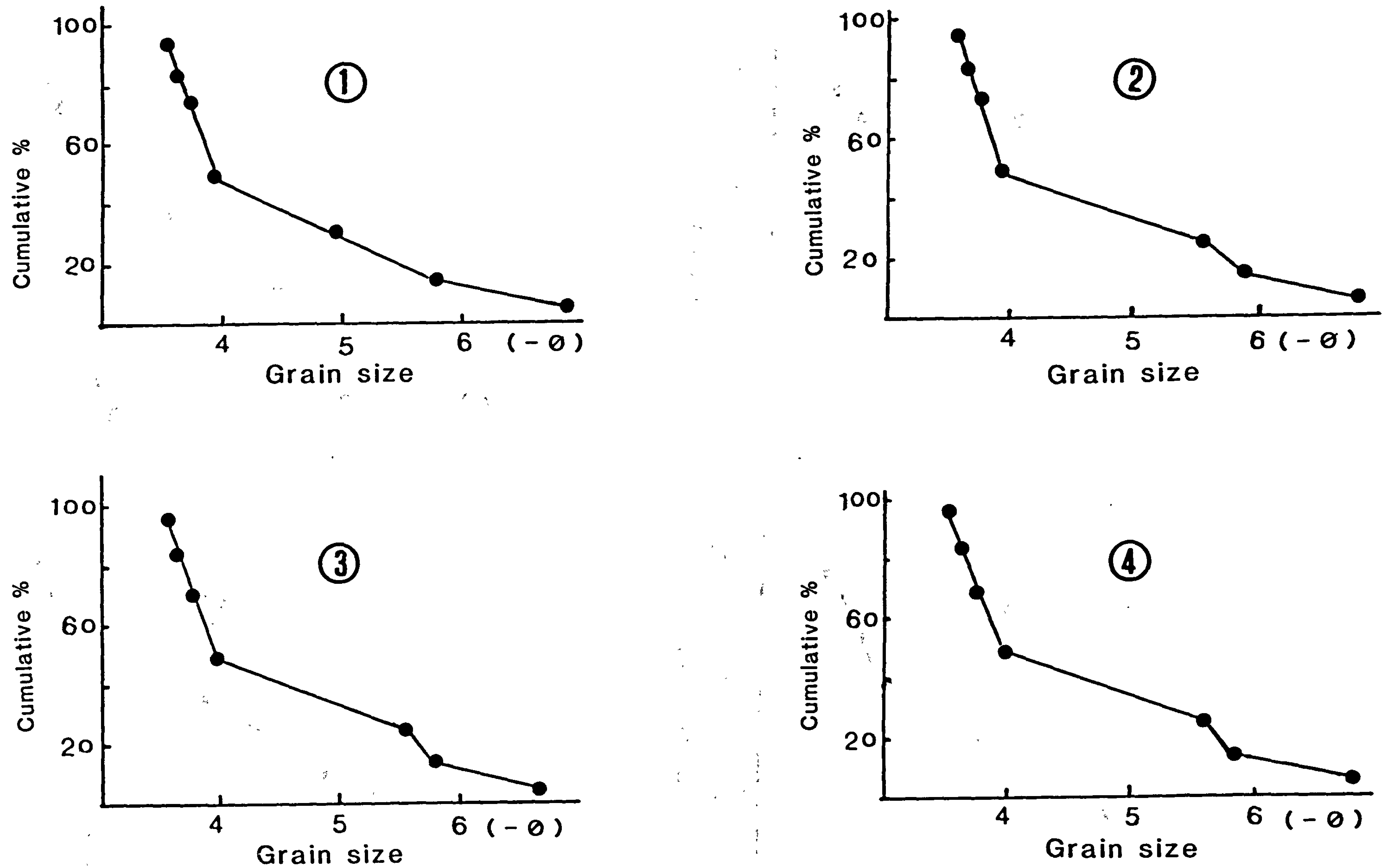


Figure 7.7 Cumulative cuNes of the grain size distribution
(numbers indicate location of the Stations in fig. 7.6)

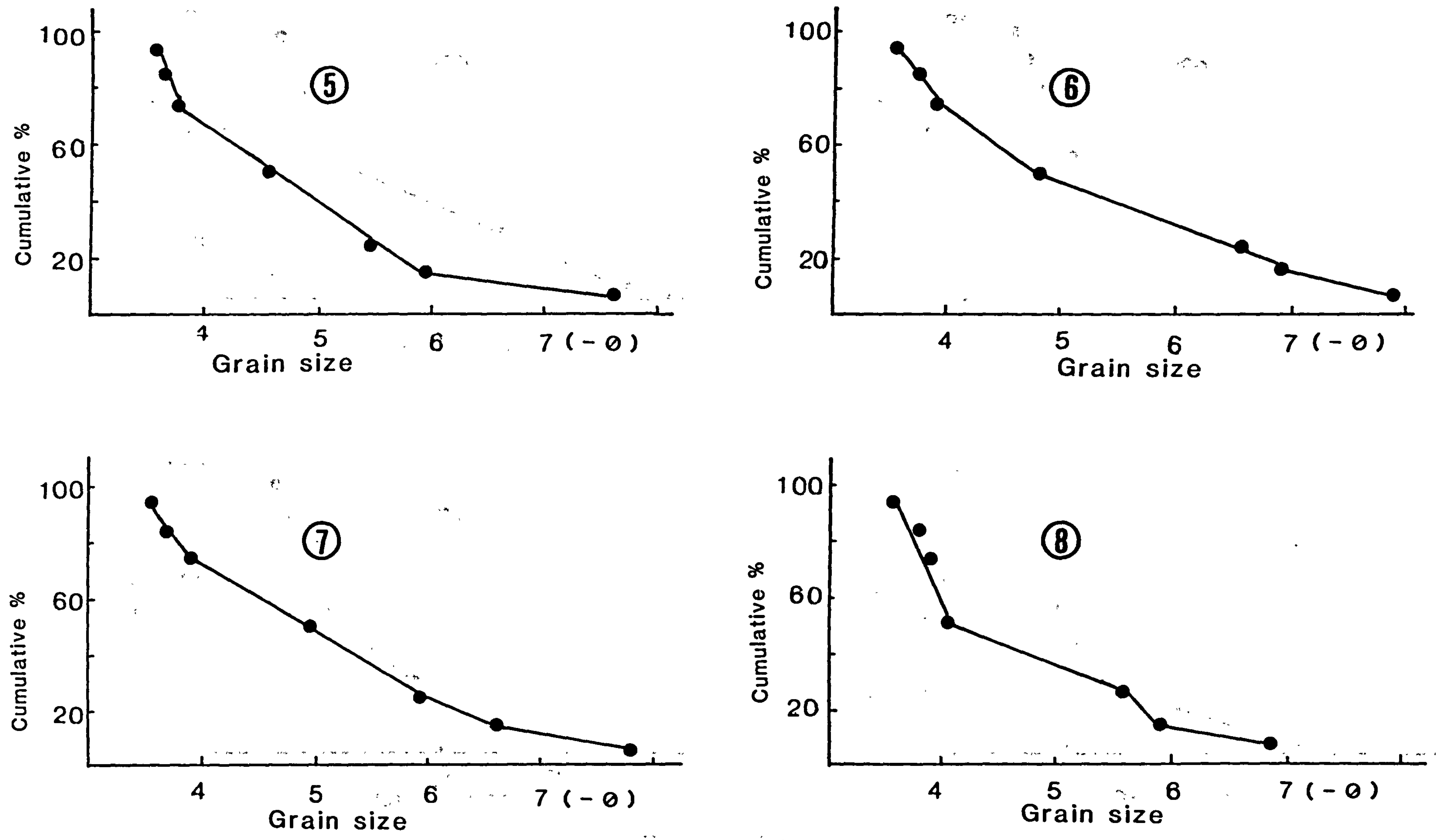
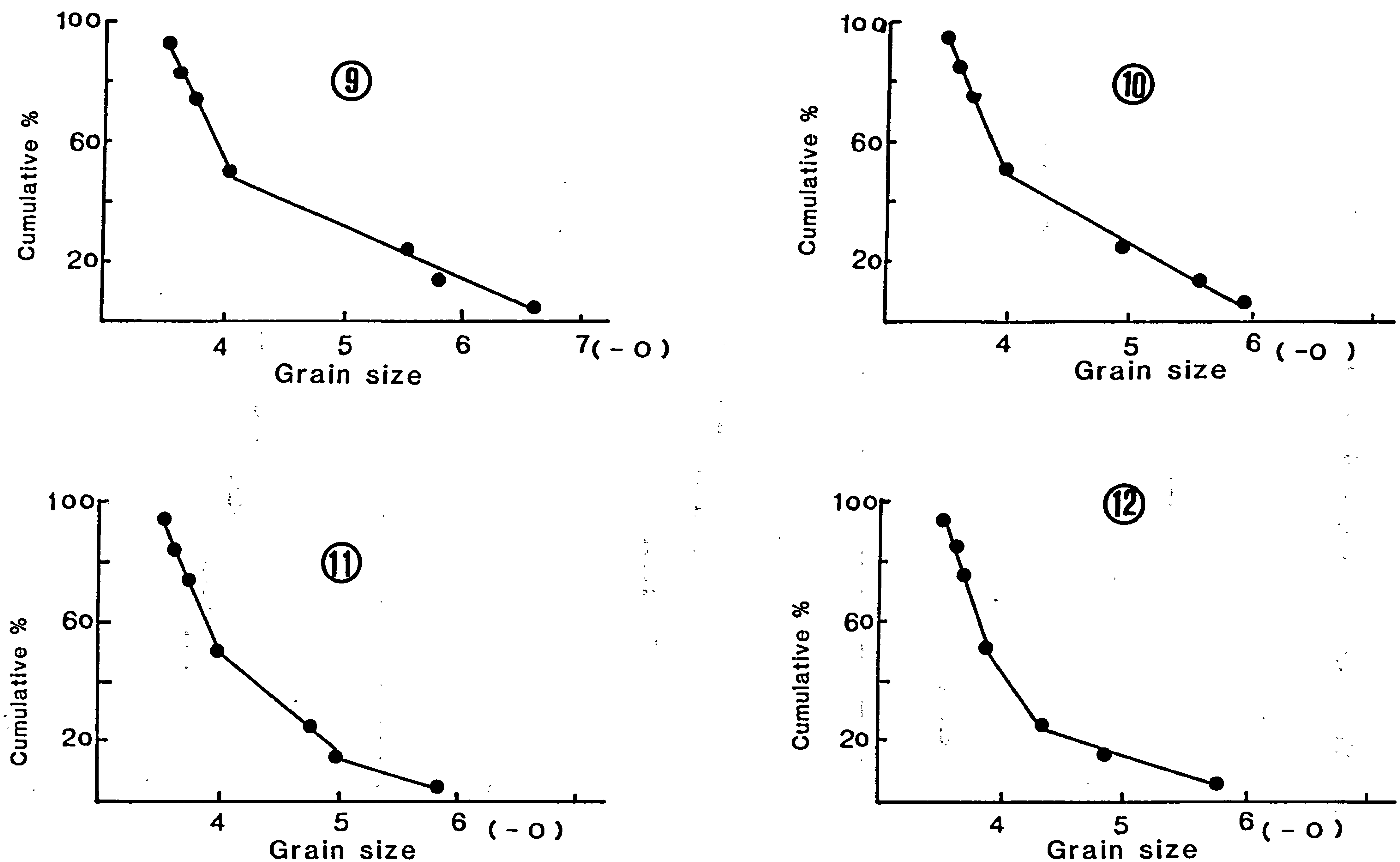


Fig. 7.7 Continue



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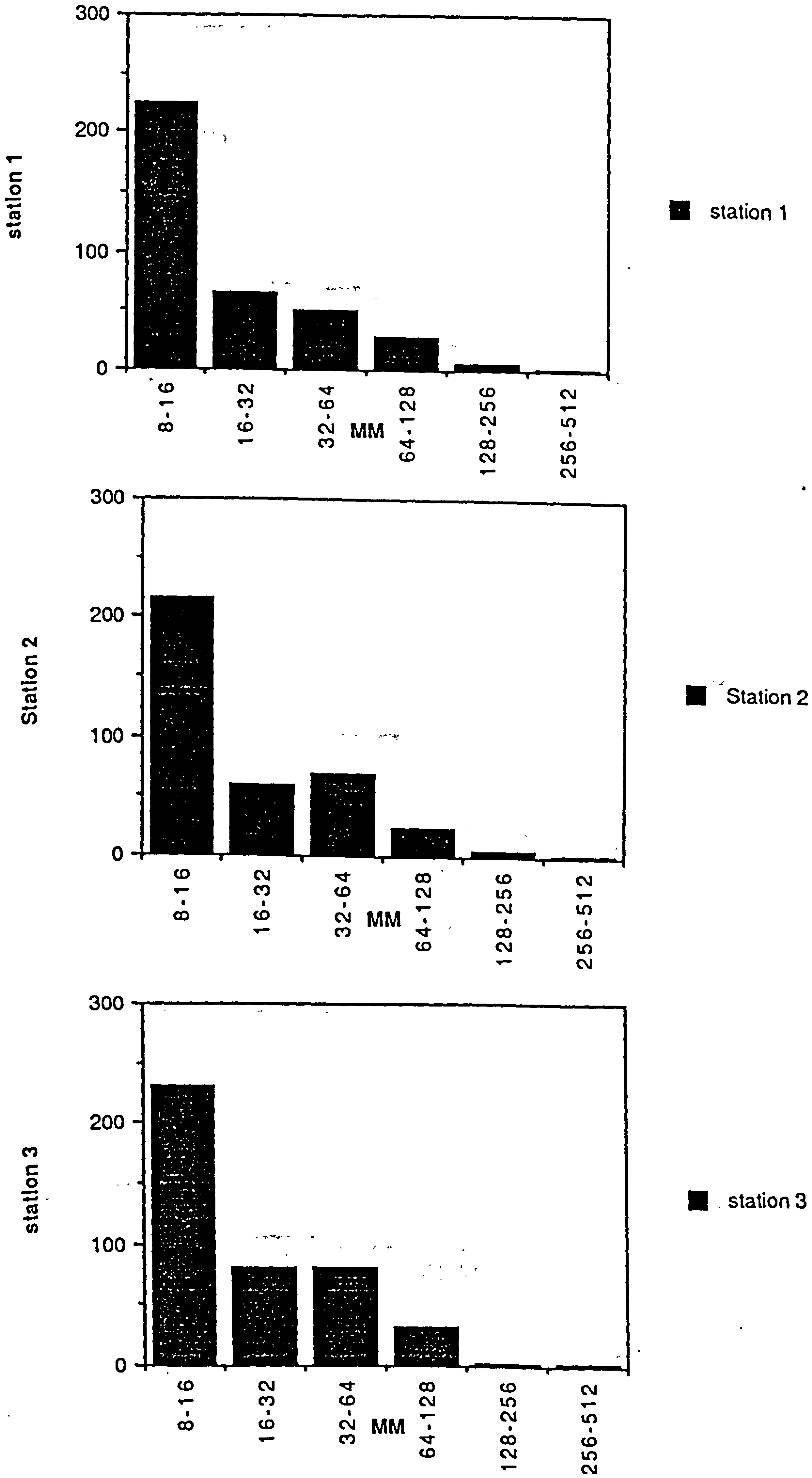
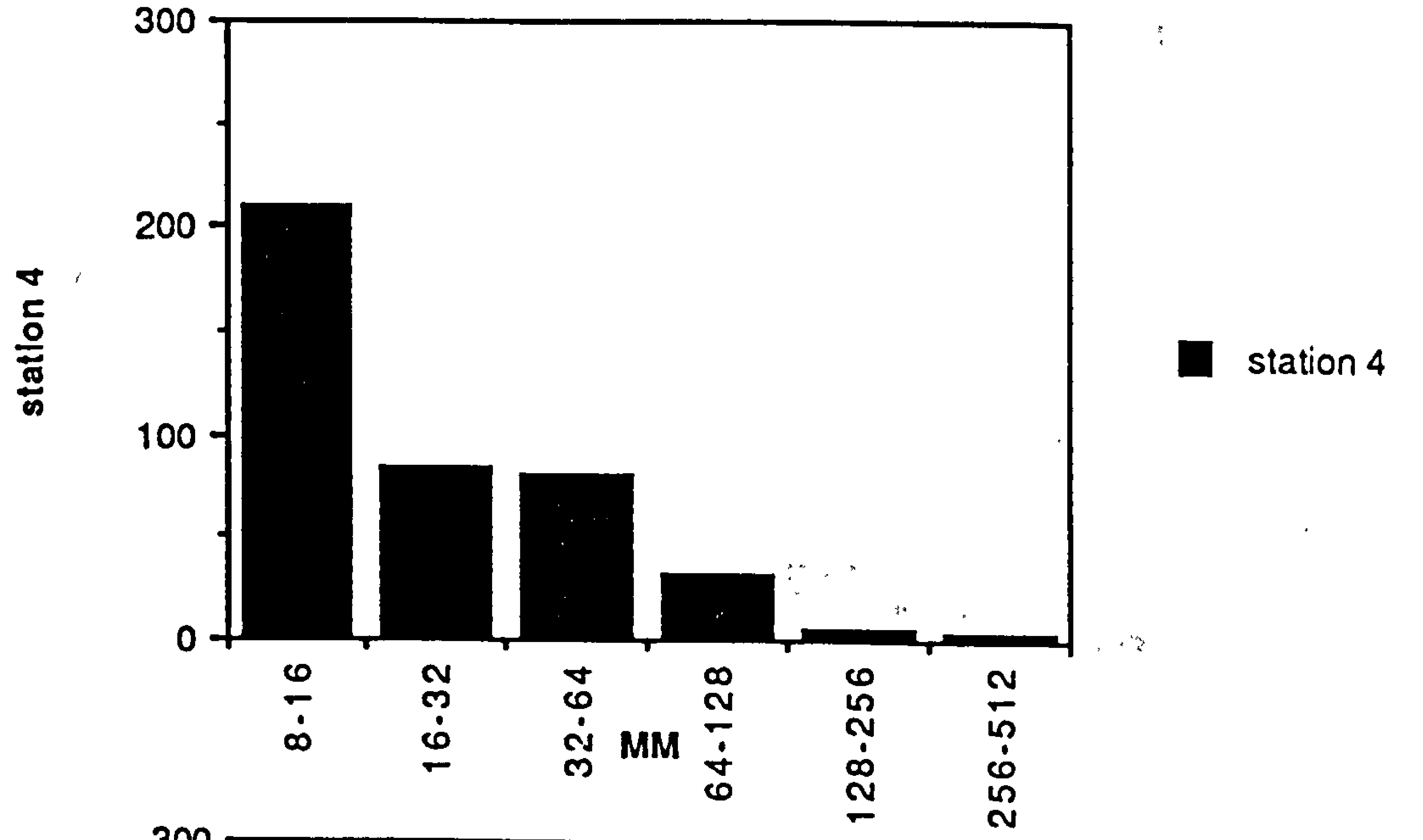
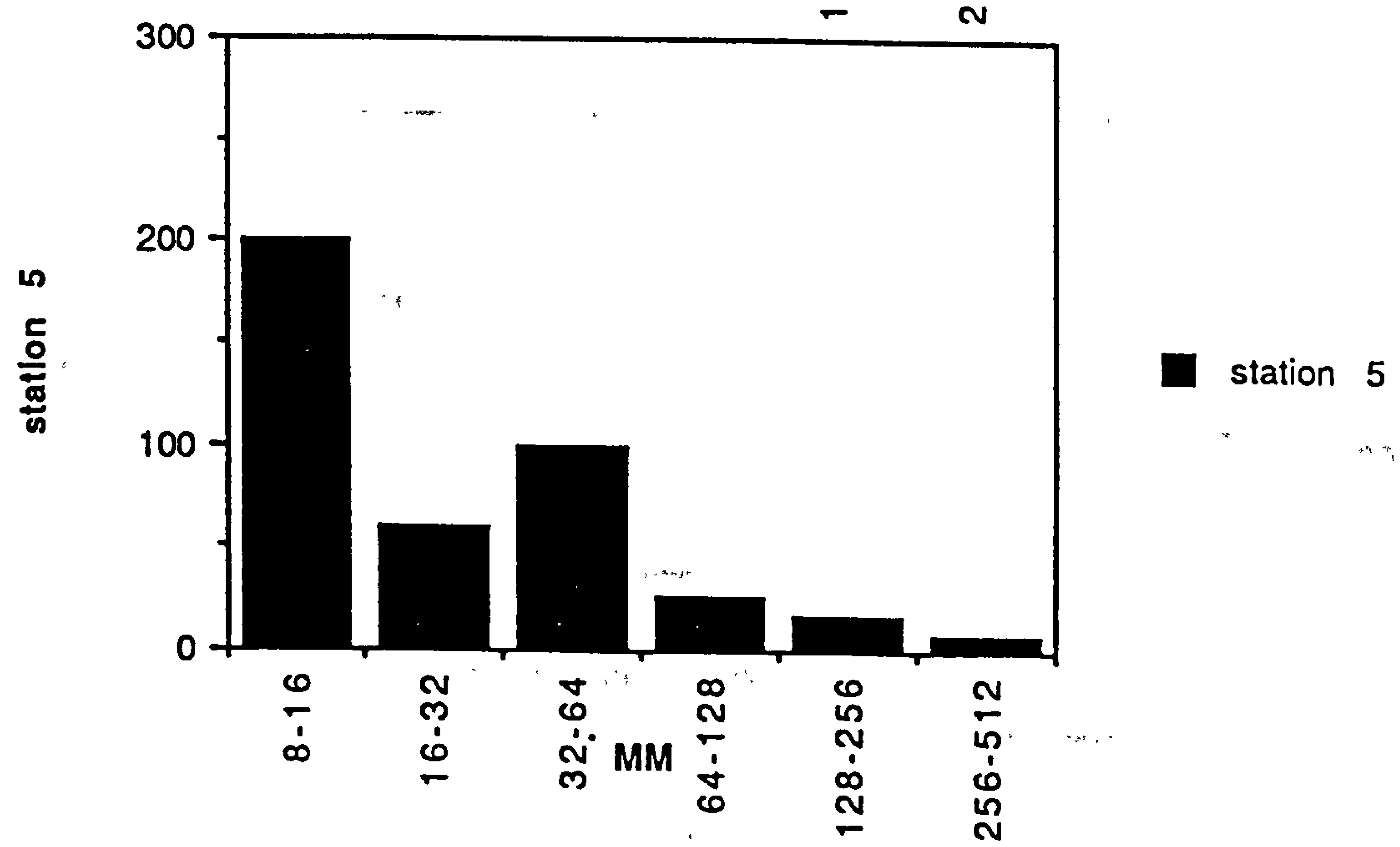


Fig. 7.8 — Histograms of the grain size distribution.





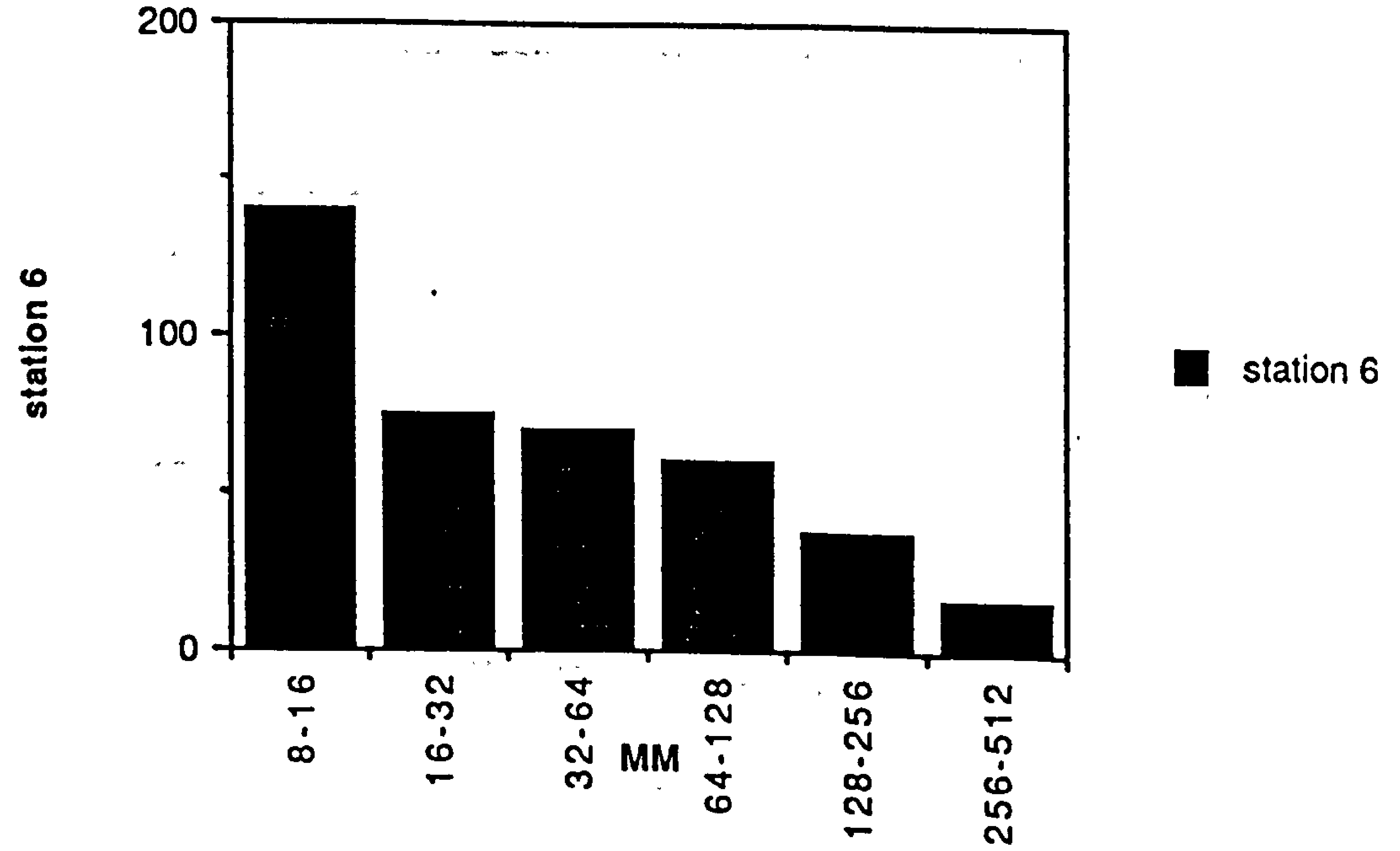
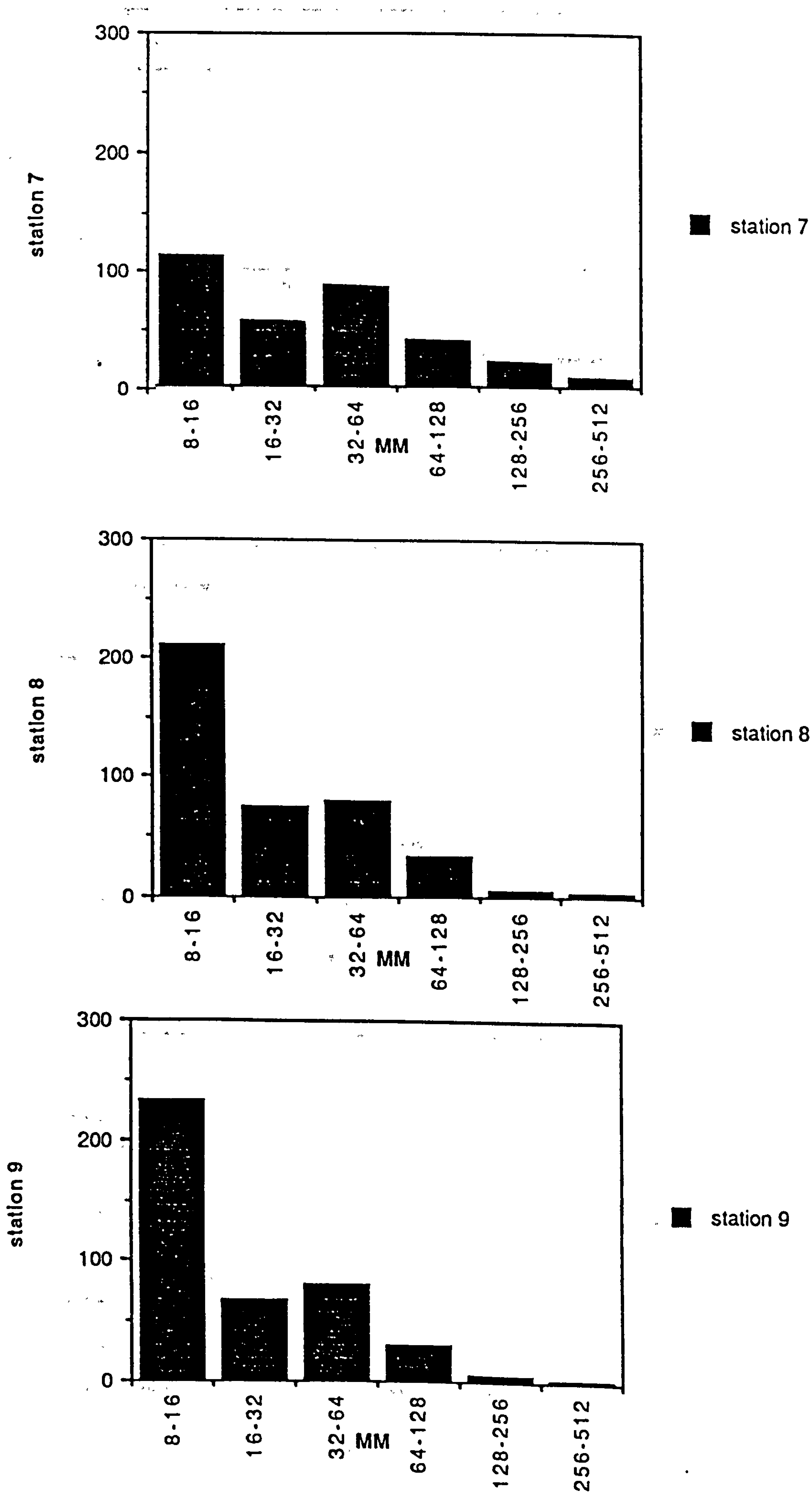


Fig. 7.8 — (Continued)



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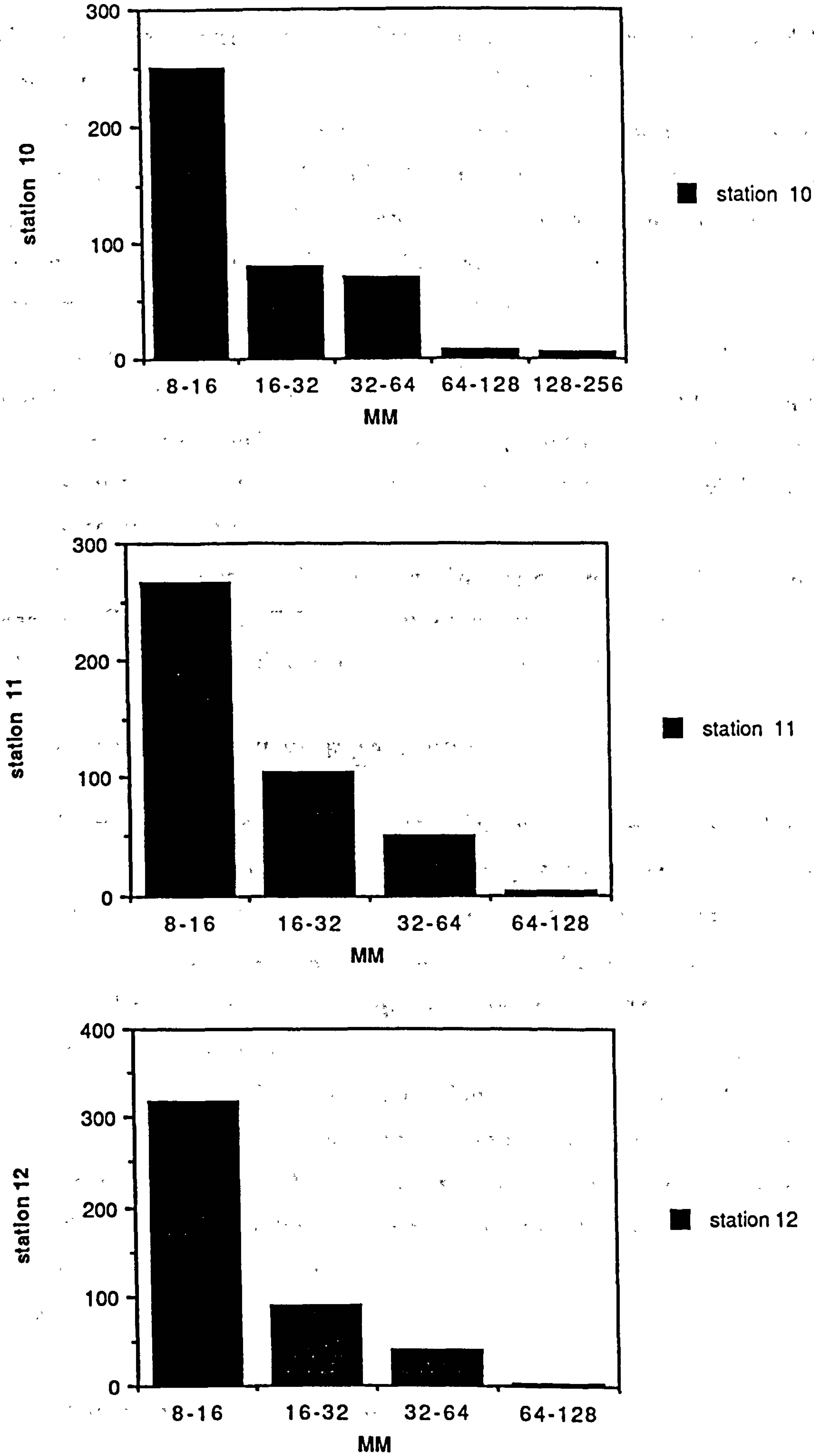


Fig. 7.8 — (Continued)

shape to the curves for the alluvial deposits, as was concluded by Bull (1963, p. 100), Hooke (1967, p. 449) and Miall (1970, p. 652).

The most prominent mode in all cases lies in the pebble range, varying from -3ϕ to -5ϕ (8–32 mm). The mean grain size ranges from -4.14ϕ to -5.37ϕ which is in the coarse pebble range. The average standard deviation is 1.17ϕ which lies in the poorly to very poorly sorted and submature grades of Folk's (1974, p. 103) classification.

As in the studies of sedimentary features of alluvial fan deposits, particularly Blissenbach (1954), Bull (1963), Hooke (1967), Miall (1970) and Nemec and Steel (1984), these values with low degree of roundness and sphericity (discussed below) suggest a typical alluvial fan for the Zangu conglomerate.

There is a noticeable decrease in grain size towards the top of the section (Figs. 7.4 and 7.5). This may be due to the reduction in the relief of the source area and/or diminution of the flow velocity.

7.4 MAXIMUM CLAST SIZE ANALYSIS

Variations of maximum clast size values are shown by isopleth maps. Since the conglomerate in the study area is exposed only in a narrow belt, this parameter was determined along the outcrop.

The apparent maximum diameter of the ten largest clasts were measured with a ruler or a tape at each station. Miall (1970) measured maximum clast size within an area of a six-foot radius. In the present study it was confined to a space of about 3 m throughout the vertical section. Mean clast size of ten largest clasts was recorded as the maximum clast size (table 7.3). As it is shown in Figure 7.9, the maximum clast size fluctuates throughout the entire length of the section, but it correlates with the variation of the conglomerate thickness (Fig. 7.10). Measurement of this parameter shows that the largest clasts are found in the area where the sequence has greatest thickness.

The maximum clast size distributions of the Zangu conglomerate reveals a direct relationship with the mean grain size distribution

Table 7.3 – Mean clast size of 10 largest clasts and the conglomerates thicknesses.

Station No.	1	2	3	4	5	6	7	8	9	10	11	12
Thickness (m)	33	30	32	35	48	56	52	45	40	35	30	20
Mean maximum clast (cm)	25	23	27	30	40	42	40	30	26	22	15	10

pattern (Fig. 7.11). This relationship also has been established by the analysis of modern unconsolidated gravels (Inderbitzen, 1959) and for the Pliocene gravels (Schlee, 1957).

Grain size analyses in the well cemented conglomerates are difficult and time consuming. It is suggested, therefore, to substitute the more easily determined "maximum size" for the grain size study in ancient alluvial deposits. Results of this measurement show a general view of the grain size distribution.

7.5 SPHERICITY

Sphericity of clastic materials has long been of considerable interest to sedimentologists. It was recognized that a precise quantitative knowledge of grain shape, sphericity and roundness may furnish valuable information about the transportational and depositional environment of the particles.

The definition of true sphericity of a particle has been stated by Wadell (1932) as

$$\text{True sphericity} = \frac{\text{surface area of a sphere of the same volume as the particle}}{\text{actual surface area of the particle}}$$

Because of the difficulty of measuring the surface area of irregular particles, various alternatives of sphericity definition have been proposed. Some workers assume the particles to be ellipsoidal in shape or take only

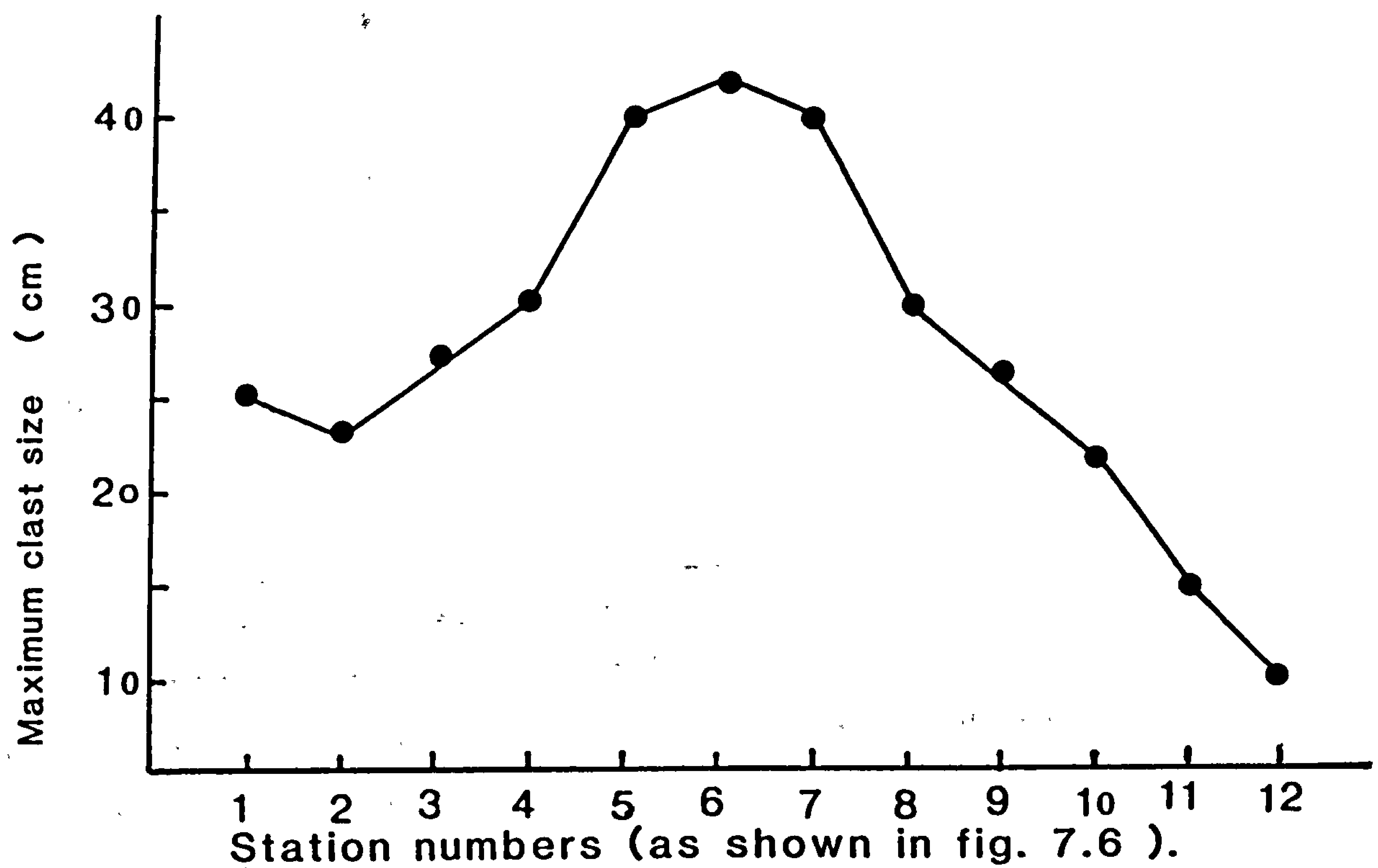


Figure 7.9- Maximum clast size along the section.

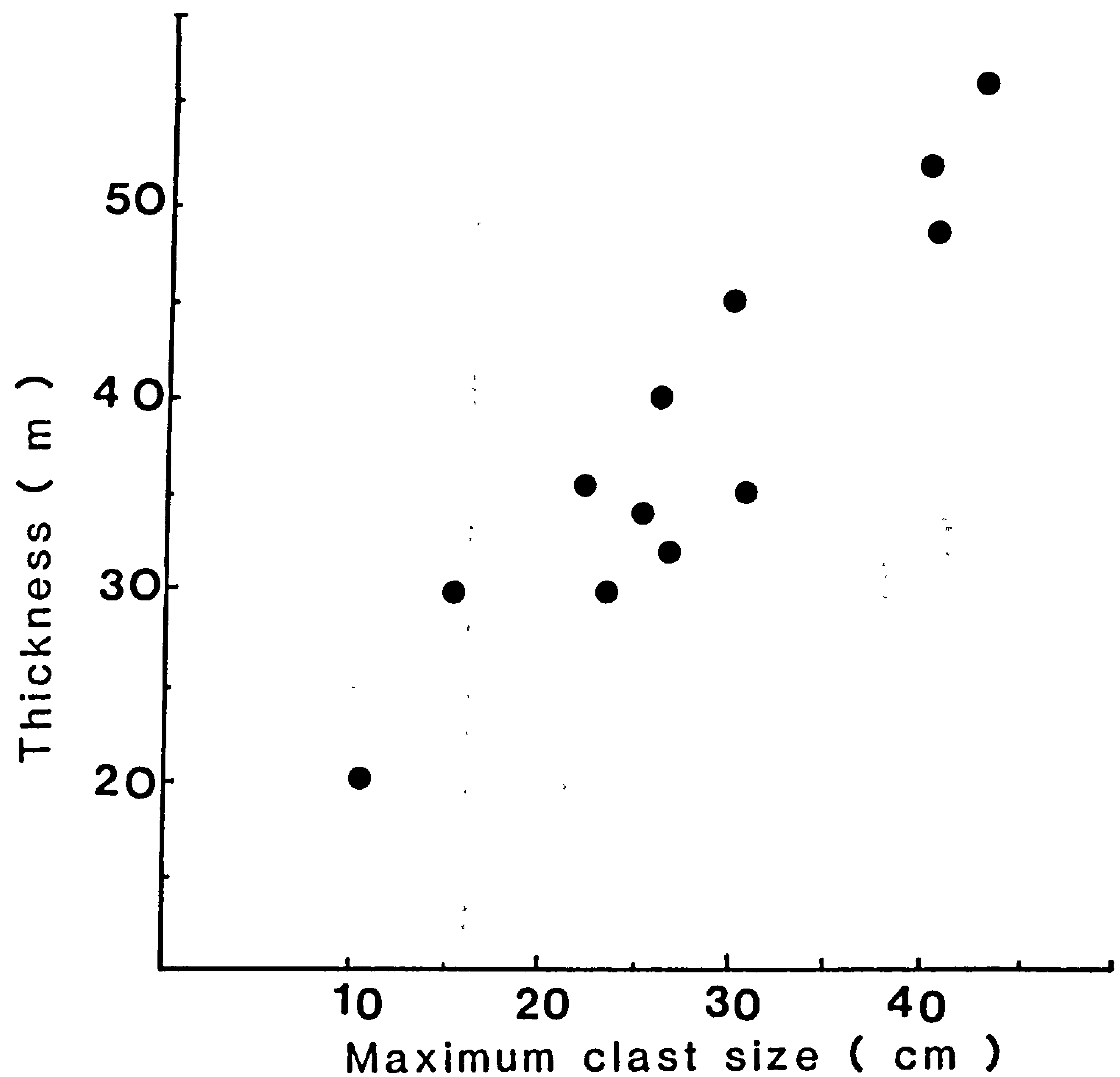


Figure 7.10- Relationship between Maximum clast size and the conglomerate thickness.

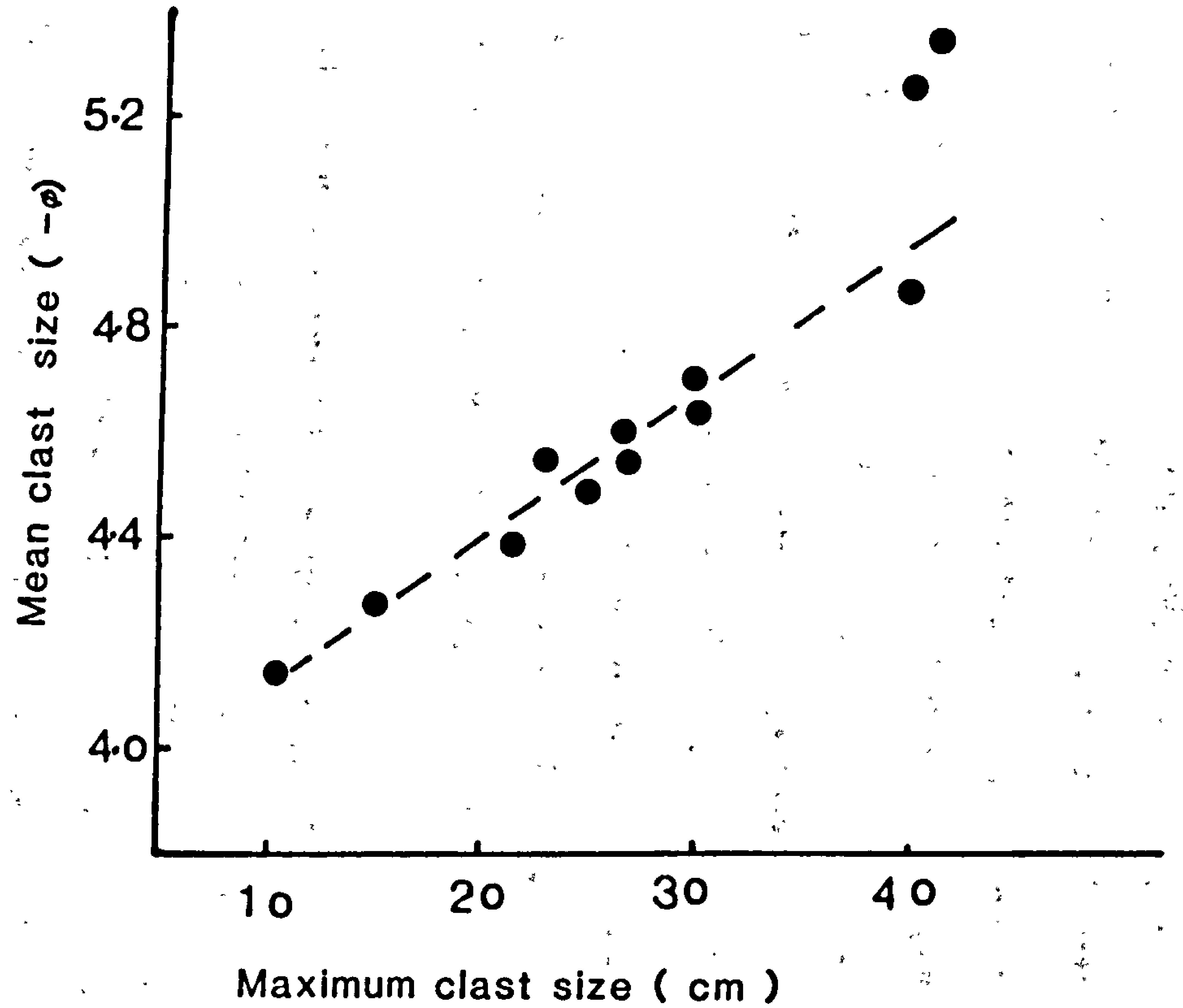


Figure 7.11- Relationship between maximum and mean clast size.

two dimensions into account. More common definitions involve three dimensional axes. Willard and Hurst (1943) determined the sphericity of a grain as the square root of the ratio of the short and long diameters of the projected image. Folk (1955) compared several developed methods and devised the medium projection sphericity $\sqrt[3]{s^2/LT}$.

However, visual methods of estimating sphericity of sedimentary particles have been proposed by various investigators. Direct measurements of sphericity of well-cemented conglomerates are tedious and time consuming, especially when many determinations need to be made. Thus Rittenhouse's (1943) visual comparison method was used for this measurement. To obviate morphological variation related to grain size and composition, determinations were made for 20 to 30 cobbles of a single lithology at each site. The cobble sizes were in the -6ϕ to -7ϕ (64–128 mm) range.

The sphericity values for the Zangu conglomerate (table 7.4) range from 0.68 to 0.72 with a mean sphericity of 0.70. No major changes in the sphericity of the particles were found.

Sphericity was determined along the vertical section at stations 4, 6 and 8 (table 7.5). The sphericity value is almost constant through measured sections. According to Blissenbach (1954), no major change is expected in the sphericity of clasts in a fan as long as there is no change in the composition or the facies of sediments.

The sphericity value found for the Zangu conglomerate is very close to the sphericity values determined by Blissenbach (1954) and Bluck (1964) for the alluvial fans in the semiarid region in southern Arizona and for an alluvial fan in southern Nevada, respectively.

7.6 SORTING

Sorting of the grains in clastic sedimentary rocks is one of the important factors for the interpretation of the palaeoenvironment. There are two methods of measuring the sorting from a section of rock: 1) direct measurement of the maximum dimensions of several hundred

Table 7.4 – Sphericity determination using Rittenhouse (1943) visual comparison chart.

Station No.	Sphericity (%)					Mean
	.55-.59	.61-.65	.67-.71	.73-.77	.79-.93	
1	0	20	30	40	10	.71
2	0	25	35	35	5	.70
3	0	20	40	32	8	.70
4	4	10	36	45	5	.69
5	0	20	30	40	10	.71
6	0	25	40	25	10	.70
7	0	25	30	40	5	.70
8	0	30	45	20	5	.69
9	4	30	36	36	0	.72
10	0	15	30	45	10	.70
11	0	30	30	40	0	.69
12	4	36	30	30	0	.68

Table 7.5 – Sphericity value through vertical section.

Station No.	Distance from the base of conglomerate (m)				
	10	15	20	25	30
4	.68	.69	.70	.67	.70
6	.70	.69	.70	.68	.71
8	.67	.68	.70	.69	.69

grains and application of statistical corrections for the effects of random sectioning, and 2) visual estimation using a comparator. The first method is the more accurate but is also the more time consuming. The second approach has the overwhelming advantage of ease and speed. Rough estimation of sorting for each site can be done in a matter of minutes rather than hours. Several visual comparators exist (Beard and Weyl, 1973; Lewis, 1984; Mansfield, 1985; and others). Harrell (1984) presented a series of visual comparators based on computer-generated artificial grain population. However, Longiaru (1987) argued that Harrell's method is based on grain-size frequency rather than grain-size weight or volume percentage and is inappropriate. He gave a series of comparators derived from volumetric lognormal populations of various degrees of sorting. Longiaru's model is based on a three-dimensional population of specified sorting and mean grain size which is applicable for a plane or thin section. His sorting comparators also conform to the sorting terminology of Folk (1966). Longiaru's visual comparators were used for the estimation of sorting of the grains in the conglomerate sequences. Comparator use generally allows rapid estimation sufficient for many types of study.

On the basis of results obtained (see table 7.6 and Figs. 7.12 and 7.13) it was determined that the conglomerate deposits in the Zangu Mountain occupy a position in the degree of poorly to very poorly sorted. The clasts are not well sorted, suggesting a short distance of transportation. However, a comparatively slightly higher degree of sorting (moderately to poorly sorted) is exhibited farther from the center of the field studied where both particle sizes and conglomerate thickness are lower (table 7.6).

Table 7.6 – Mean grain size distribution and degree of sorting.

Site No.	1	2	3	4	5	6	7	8	9	10	11	12
Mean grain size ϕ	4.50	4.56	4.58	4.66	4.87	5.37	5.23	4.68	4.59	4.39	4.26	4.14
Degree of sorting	0.90	1.10	1.15	1.30	1.65	1.89	1.80	1.50	1.0	0.85	0.78	0.75

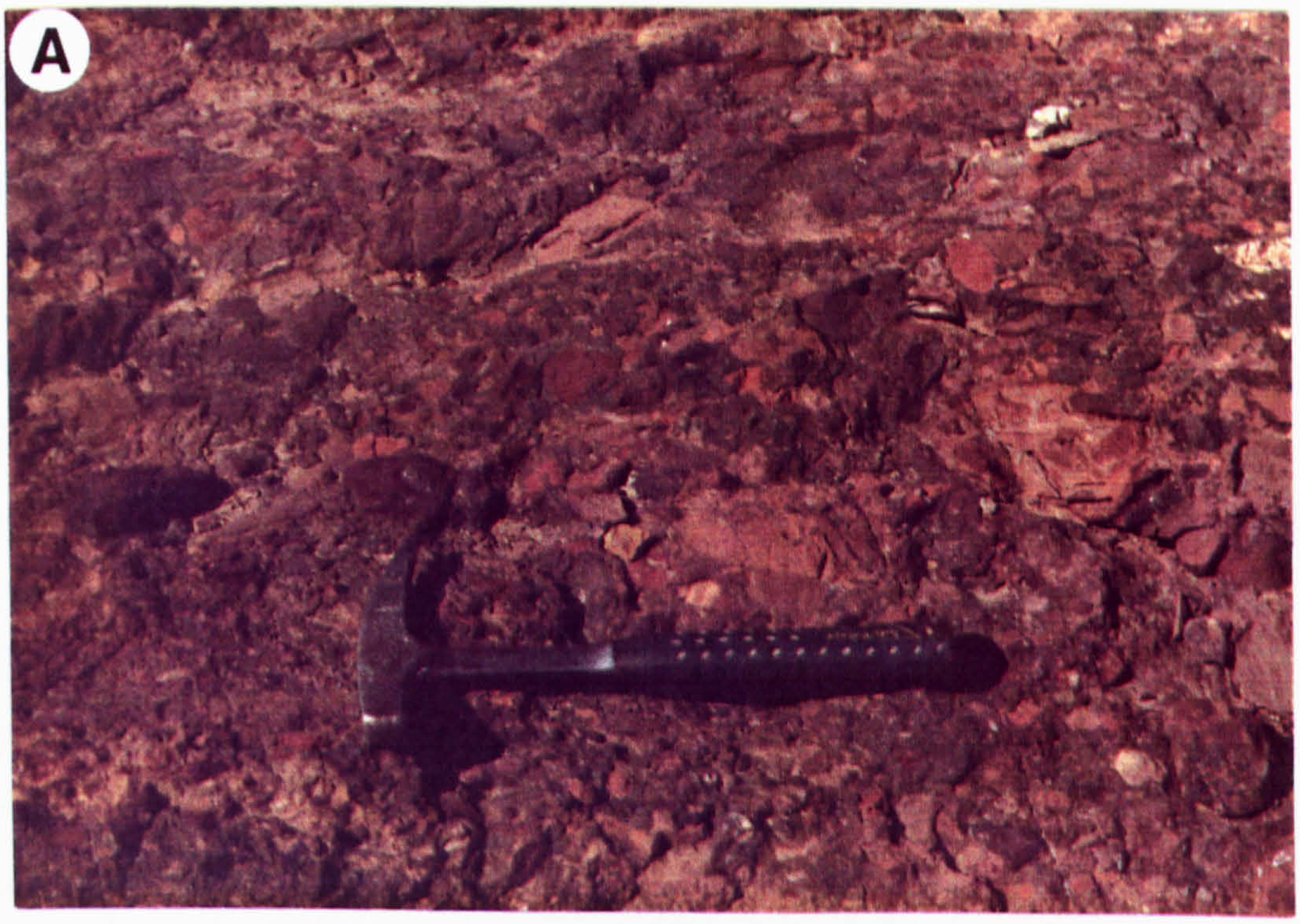
The relationship between the mean grain size and degree of sorting is shown in Fig. 7.14. Variations of these two parameters of the conglomerate in the Zangu Mountain are almost correlative, and only a few deviations from the principal trend are observed, possibly reflecting slight changes in the sedimentary environment.

Fig. 7.12 (A) Representative conglomerate texture, showing it to be poorly sorted, clast supported. Reddish brown clasts are rhyolite from underlying rocks.

Location: Station 4, about 4 m above the base of the unit.

Fig. 7.13 (B) Poorly sorted conglomerate, angular to subangular and oriented grains. Large clasts are boulders of underlying rocks.

Location: Station 6, about 17 m above the base of the unit.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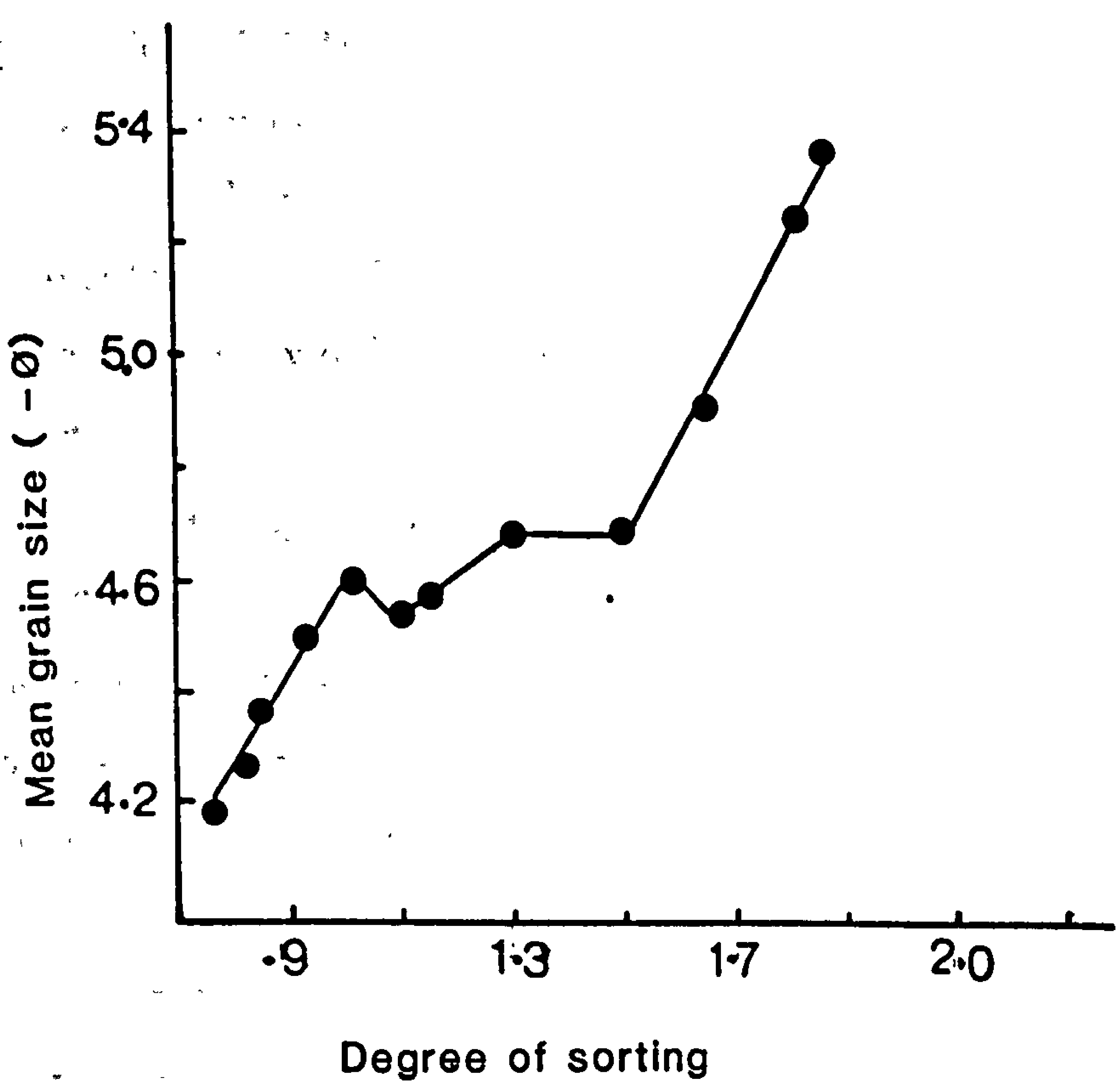


Figure 7.14– Relationship between mean grain size and degree of sorting.

The sorting value in the Zangu Mountain varies from 0.75 to 1.89 with an average of 1.23 phi units. This is close to that found (1.3 to 2.7) by Lusting (1965) for modern fan deposits in Deep Spring Valley, California. Bluck (1967) in a study of Devonian alluvial fans in the Clyde area obtained values ranging from 0.72 to 1.15 phi units.

7.7 ROUNDNESS

Early attempts to estimate roundness of the grains in clastic sediments were based on visual comparison scales, applying ten grades of pebble roundness. Visual comparison charts have been developed by Krumbein (1941), Powers (1953) and Lees (1964). Direct quantitative measurement techniques were suggested by Wentworth (1919), followed by Wadell (1933), Kuenen (1956) and others. Dobkins and Folk (1970) proposed a new quantitative method of roundness measurement using a plastic overlay sheet containing a nest of concentric circles placed at $\sqrt{2}$ intervals. Folk (1972) pointed out that the errors in direct measurement of roundness would be approximately the same as using a comparison chart.

Direct measurement of roundness in well cemented clastic sediments is difficult and tedious, thus this parameter was determined using visual comparison charts from Krumbein (1941). This method is fast and accurate enough with significant results (Folk, 1972). A limited number of measurements of roundness were made on the conglomerate sequence along its north-south extent (table 7.7). Measurements were made for 20 to 30 clasts of a single lithology in the -6ϕ to -7ϕ range (64–128 mm) at every station. Most clasts were of pink rhyolite and granite porphyry rock fragments from the underlying rocks. They are the most abundantly represented as cobbles in this unit. A number of measurements (3 to 5) were also made for the other grains present.

The rates of clast abrasion and resultant roundness commonly are affected by particle size and composition as well as by the mode of transportation. The minimum roundness of fragments in the Zangu

Table 7.7 – Roundness of clast size between -6ϕ to -7ϕ using Krumbein (1941) scale.

Station No.	Roundness (%)				Mean Roundness
	.4	.5	.6	.7	
1	10	40	50	-	.54
2	-	25	70	5	.58
3	-	40	50	-	.56
4	-	30	70	-	.57
5	-	20	70	10	.59
6	-	10	70	20	.61
7	-	20	60	20	.60
8	-	30	50	20	.59
9	-	20	70	10	.59
10	-	40	55	5	.56
11	10	30	60	-	.55
12	20	15	65	-	.54

conglomerate is 0.54 at stations 1 and 12 with the lowest conglomerate thickness and finer grain size particles. The maximum roundness is 0.61 at the point with highest conglomerate thickness and maximum grain size.

The roundness distribution curves (Figs. 7.15 and 7.16) indicate that there are some linear relationships between the roundness and maximum particle sizes as well as conglomerate thicknesses. The roundness ranges from 0.54 to 0.61 with a mean of 0.57. Roundness was determined within the vertical direction of the sequence at stations 6 and 7. The value of this parameter shows slight decrease upwards and can be attributed to the upward fining of the clasts. This property in the clasts of the study area thus indicates alluvial fan deposits (Dobkins and Folk, 1970).

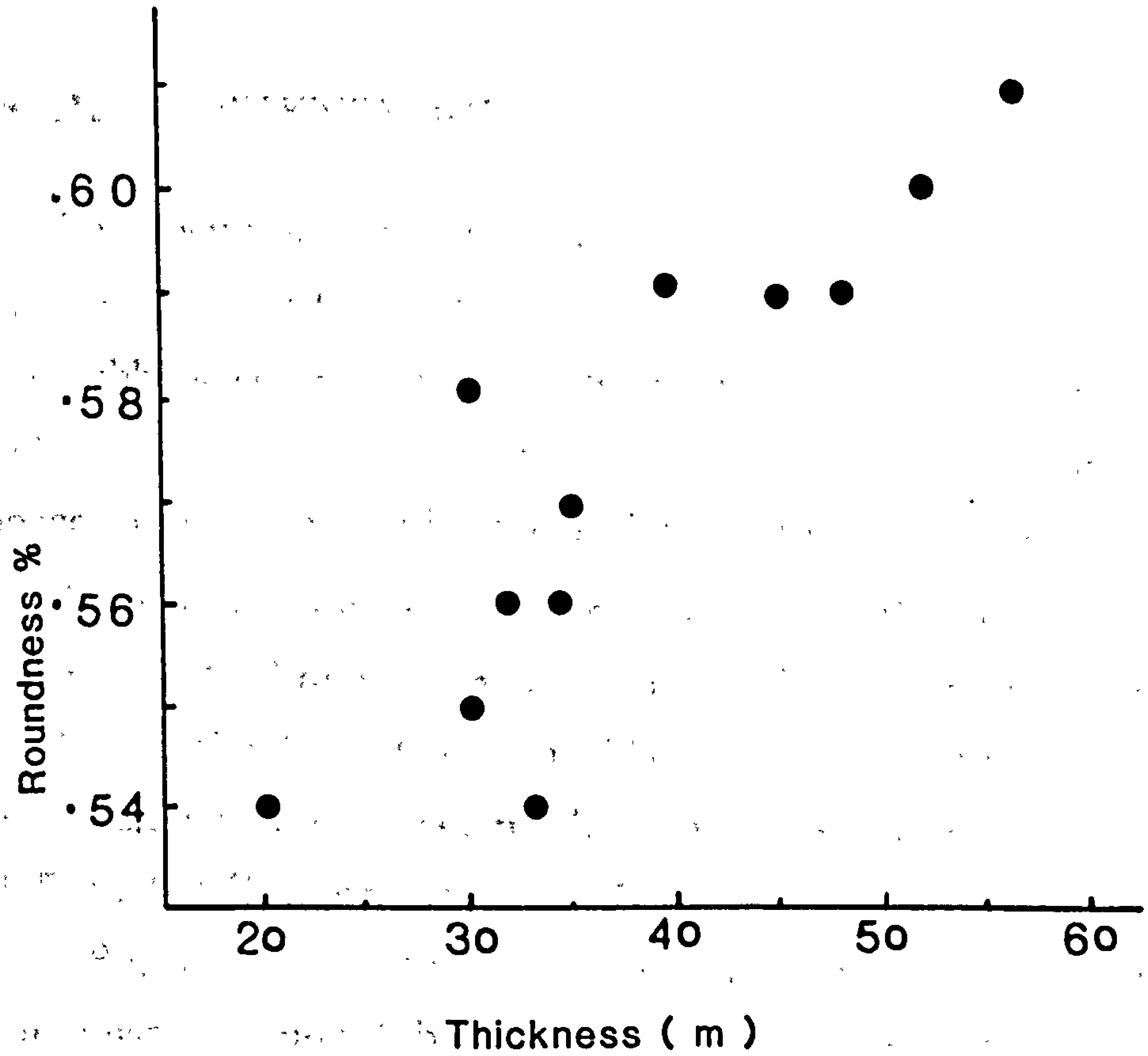


Figure 7.15- Relationship between conglomerate thickness and roundness.

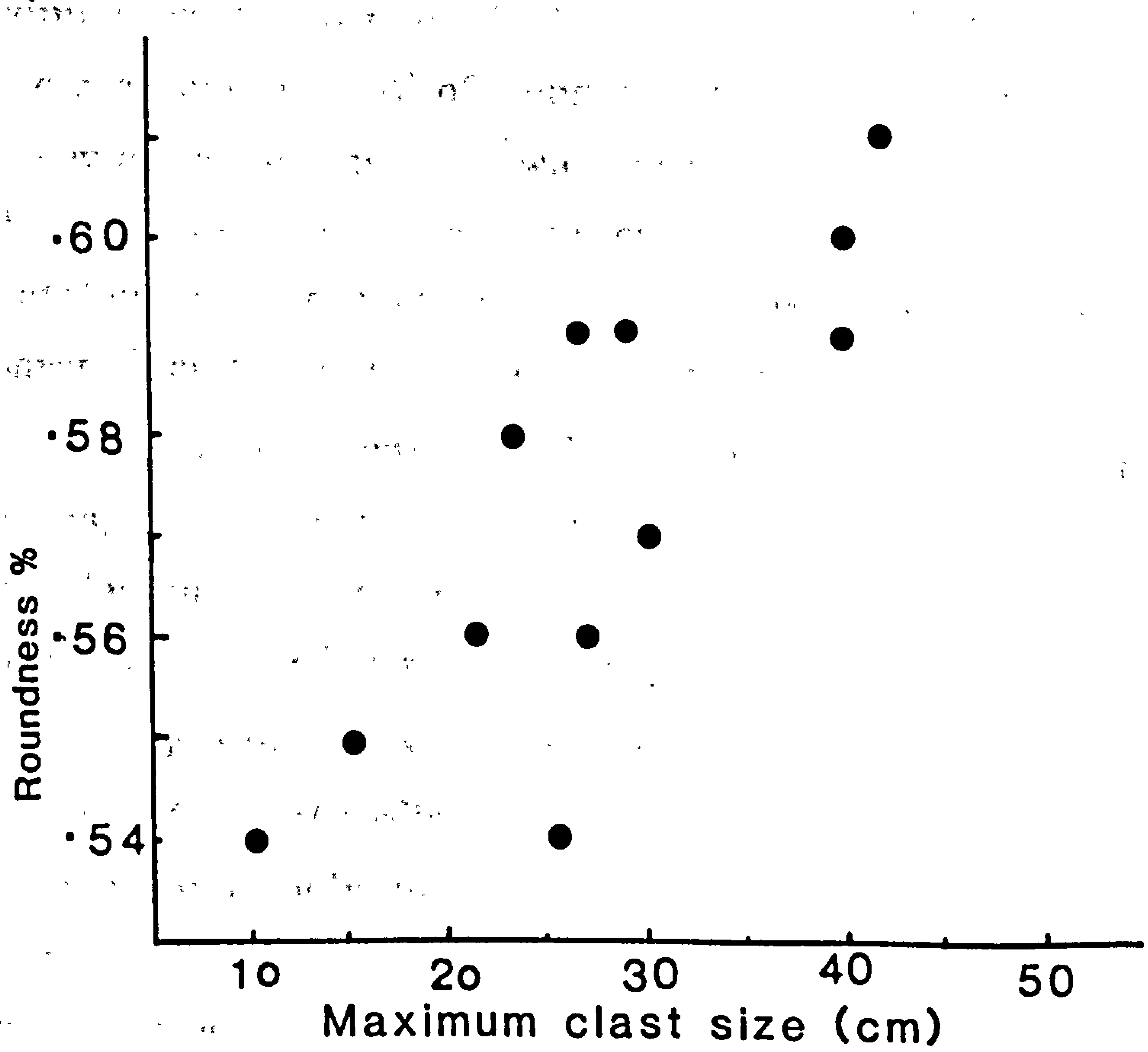


Figure 7.16- Relationship between maximum clast size and roundness.

7.8 CLAST ORIENTATION

Palaeocurrent analysis has long been regarded as an important indicator of sedimentary environments. It is well established that cobbles and pebbles commonly produce oriented fabrics. Clast orientation is a useful element in the study of palaeocurrents in conglomerates and coarse fluvial deposits in which directional structures are rare.

Several authors, e.g. Krumbein (1940), Schlee (1957) and Waay and Ogren (1984), have described preferred alignment (A-axis) consistently parallel to the flow direction. This fabric is produced by highly viscous flow such as glacial ice, mud, debris and in torrential flow (Pettijohn, 1975, p. 69; Walker, 1975, p. 137). Others (e.g. Doeglas, 1962; Blatt et al., 1980, p. 123) suggest that the alignment of pebbles tranverse to flow is a most common fabric, especially in alluvial and shoreline deposits. However, many conglomerate deposits show no preferred orientation; this happens during very rapid sedimentation in which the clasts are not able to react to the current (Lindholm, 1987, p. 61).

Grain orientation is commonly measured as the angle and dip of the maximum projection plane (AB) of disc-shaped clasts, or as the azimuth and dip of long axis (A) of elongate clasts. In palaeocurrent studies for the flow direction it is not always necessary to measure vector means of both A axis and AB dip orientation (Rust, 1972). In this exercise clast orientation was documented by measuring the orientation of the apparent long axis of each clast on the bedding plane.

Although more extensive data give a more accurate palaeocurrent analysis, some 20 readings for each locality in a small area is sufficient when dealing with a unimodal current system, but for a polymodal current system further readings are needed (Tucker, 1984, p. 39).

Clast orientations were measured on sample areas of the bed surface roughly 0.64 m^2, regardless of the grain size. The long-axis orientations were measured only for the elongate clasts (a/b ratio of 1.5:1 and greater). All the sample locations consisted of at least 20 sufficiently elongate items for measurement (Fig. 7.2b). Since the structural dip is less than 25°, the measured angles of linear orientation need no correction (Potter and Pettijohn, 1963, p. 262). Determinations were made at 12 locations distributed throughout the outcrop of the study area (Fig. 7.6).

The orientations of the long axes of 240 clasts were measured (Table 7.8). Directional data presented here range between 0 to 50 degrees. Most of the clast orientations are less than 30°. A class interval of 10° was used.

Table 7.8 – Long axis clast orientation (N ... degrees E).

Site No.	Clast orientation (°) 0-14		15-29		30-44		45-60		Vector Mean
	No.	%	No.	%	No.	%	No.	%	
1	2	10	10	50	7	35	1	5	27.7
2	2	10	8	40	10	50	-	-	28.5
3	1	5	7	35	22	55	2	5	32.5
4	-	-	6	30	22	60	2	10	34.5
5	-	-	9	45	7	35	4	20	33.5
6	2	10	8	40	8	40	2	10	30.0
7	2	10	6	30	8	40	4	20	32.7
8	3	15	7	35	10	50	-	-	27.8
9	4	20	6	30	8	40	2	10	33.5
10	-	-	8	40	10	50	2	10	33.0
11	2	10	8	40	7	35	3	15	30.7
12	4	20	10	50	4	20	2	10	26.0

Percentages of observations in each class interval are plotted rather than total number of observations. Clast orientation measurements are presented by rose diagrams, as in Figure 7.17.

Alignment of elongate pebbles transverse to the flow direction is the most common fabric in rudaceous sediments, especially in alluvial fan deposits. In previous studies of modern gravel and ancient conglomerates, the transverse long axes of clasts have been taken to indicate the flow direction. Applying this interpretation to the fabric data

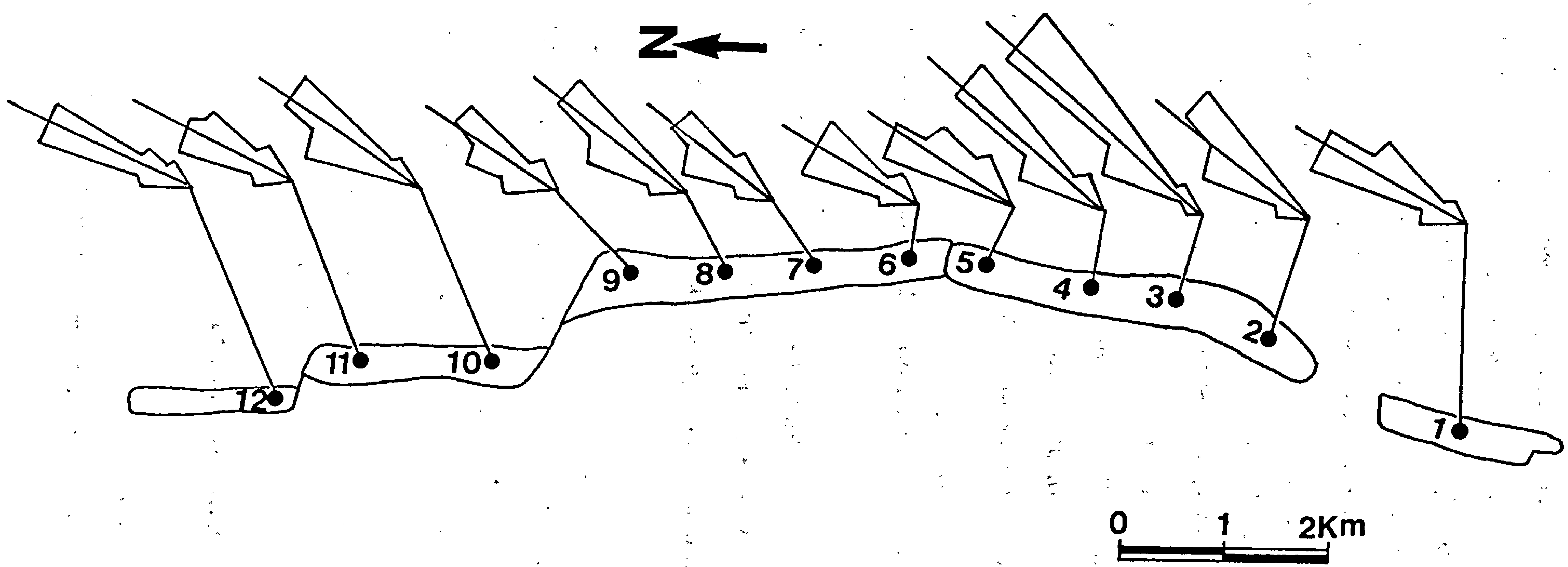


Fig. 7.17 - Clast orientation diagrams for locaions 1-12.

from the Zangu Mountain conglomerate, the writer infers that the dominant flow was to the northwest.

7.9 DEPOSITIONAL ENVIRONMENT

Alluvial fans are mainly developed in arid to semiarid regions where terrestrial vegetation is scant. Thus they were probably more widespread in Devonian and earlier times (Cotter, 1978). Criteria for the recognition of ancient fan deposits are discussed by several authors (Blissenbach, 1954; Miall, 1970; Rust, 1978), viz:

a. The body of an alluvial fan is made of coarse detritals ranging from boulder to clay size with a rapid change in the matrix or mean particle size.

b. Arkoses or greywackes are the main matrix components.

c. Fragments in the alluvial fan deposits are angular, subangular or subrounded and the coefficient of sorting ranges from about 1.5 to 3.0.

d. In these sediments imbrication is pronounced, with inclination commonly 30° or less to the south.

e. Alluvial-fan deposits have good to poor stratification and the original dip of the strata may be steep, low or zero. Based on the results of the present analysis, the Zangu conglomerate represents a single, perhaps isolated, alluvial fan.

An idealised alluvial fan resembles geometrically a segment of a cone. Blissenbach (1954) designated three sections: the apex, the midpoint and the base. Miall (1981) divided an alluvial fan drainage system into four parts: (1) headwaters in upland source area; (2) proximal environments, immediately below the fall line; (3) medial environments; (4) distal environments (base), where the rivers interact with a terminating environment such as delta fronts, playa systems, tidal flats and so on. In regard to the sedimentary features of the Zangu conglomerate only medial and distal environments of the drainage system are prominent. The sedimentary texture of the conglomerate unit suggests a subaerial depositional environment. Texture alone cannot be used for distinguishing fluvial conglomerate from shoreline or nearshore conglomerates. However, textural maturity, such as (a) amount of matrix retained in the framework, (b) degree of sorting, and (c) roundness of clasts, is reflected mainly in the mode of discharge and degree of contemporaneous reworking. Texturally immature gravels are representative of alluvial fan stream deposits originating in ephemeral (flash) flooding systems (Nemec and Steel, 1984). The conglomerate in the Zangu Mountain shows widespread clast imbrication and lack of well defined stratification. The clast imbrications reveal a unimodal flow system with a SE-NW flow prevailing.

The clasts dip to the south and thus a transverse direction was supposed for the flow regime. Therefore the source area was to the southeast. The flow direction and the source area are coincident with the proposed palaeogeographic map of the Devonian outcrops in Iran (see Fig. 2.4).

7.10 DEPOSITIONAL MODEL

Nine major basin models which are most likely to be found in practice were defined by Miall (1981). His model of a transverse fan system can be applied for the Zangu conglomerate. The only difference is that Miall's model illustrates several alluvial fans but the Zangu unit indicates a single alluvial fan body (Fig. 7.18). The run-off was probably ephemeral with a short intermittent flow regime.

Poor sorting with subangular to subrounded clast materials possibly suggests that the surface area at the source rocks had a relatively high relief (around 10°) but lower relief (less than 4°) at the base of the fan. This sedimentary pattern is common in graben basins such as Death Valley, California (Hooke, 1972). A Devonian example of such a sedimentary pattern was identified by Miall and Gibling (1978) in Somerset and Prince of Wales Island, NWT, Canada.

The Zangu conglomerate tends to display upward fining in the upper portion of the section (see Fig. 7.4). Upward fining has been documented for braided stream type deposits (Nemec and Steel, 1984), but such sequences may simply represent deposition due to slight fluctuation in the stream velocity.

Most modern alluvial fans are in areas of Recent tectonic activity (Blissenbach, 1954; Rust, 1978). Zangu conglomerate indicates local uplift (prior to the Late Devonian); however, the extent of the uplift is unknown. The earliest preserved sedimentation above the "Infracambrian" basement consists of the infilling of topography by red shale. As mentioned earlier, the upper surface of the shale is truncated and irregular and particles of shale are found within the conglomerate showing that the shale was eroded prior to conglomerate sedimentation.

It is likely that the Kerman area was uplifted during the Late "Infracambrian" Orogeny and the red shale then formed as a sequence of local soil accumulation and dispersal. The period between shale deposition and alluvial fan is of unknown length.

The conglomerate on top of the shale indicates either a climatic change or a change in the relief as a result of local uplift.

In a nonmarine basin within or adjacent to uplift, rivers tend to run either normal or parallel to the structural strike (Miall, 1981). In the Zangu Mountain, the flow direction was transverse to the strike of the uplifted source area.

Alluvial fans commonly have surface gradients of less than 10°. The radius of Recent fan deposits in southwestern North America are typically between 0.5 and 7 km (Allen, 1965). The lower surface of the Zangu alluvial fan has a gradient of about 3° to 5° with a radius of about 9 km with a cone shape.

The conglomerate is overlain by fine grained sandstone followed by carbonate deposits. In the examined profiles there is no evidence of strong mechanical reworking or erosion on the upper surface of the conglomerate. These suggest a transgression over this part of the region

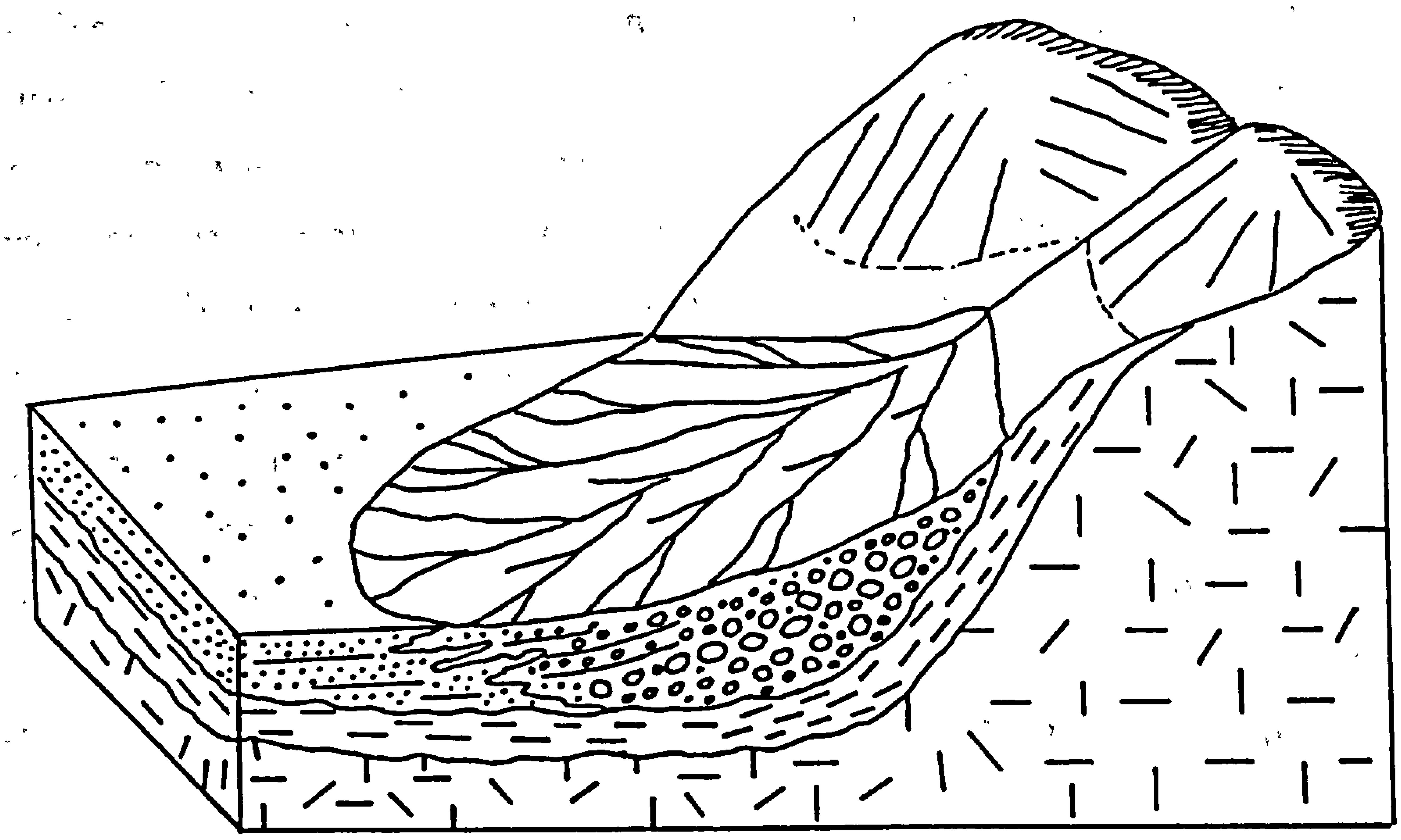
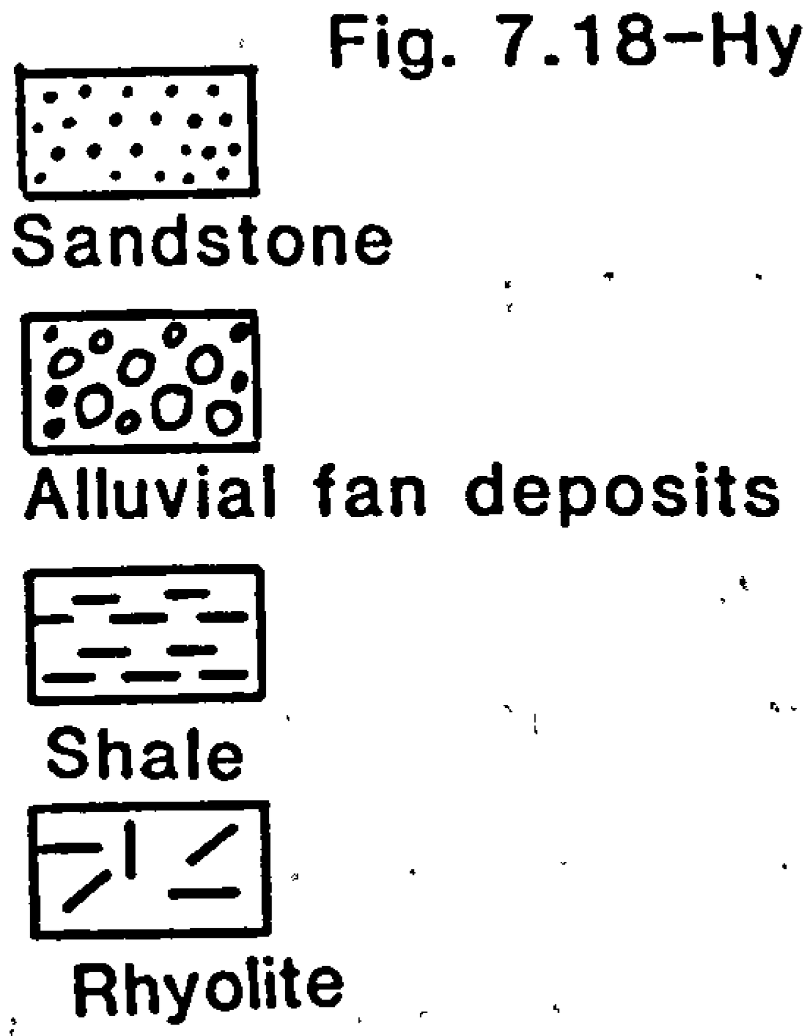


Fig. 7.18–Hypothetical model of the Zangu alluvial cone.



or decreasing of the elevation of the source area.

The rate of sedimentation of an alluvial fan depends upon the relief of the source area, climate, annual rainfall and vegetation. Estimation of rate of accumulation of sediments is thus uncertain, but at least gives some idea of the time required for a fan sequence to form. Hooke (1968), in a study of alluvial fans in California, estimated the variation of rate of deposition between 24 and 45 cm/1000 years. Beaty (1970) found that the rate of accumulation ranges from 7.5 to 15 cm/1000 years. On the other hand, the average rate of sedimentation calculated by Hooke (1972) for Death Valley, California, is about 86 cm/1000 years.

Assuming similar conditions for the Zangu alluvial deposition to those of the Recent of California, and calculating the average estimated accumulation, the rate of deposition would be about 48 cm/1000 years for the Zangu conglomerate. The estimated rate of accumulation of the conglomerate body suggests a period of approximately 200,000 years.

7.11 SUMMARY AND CONCLUSIONS OF CONGLOMERATE STUDY

Results of this study of the Zangu conglomerate are summarized below:

1. The lithofacies of the deposits is a clast-supported coarse grain pebble texture conglomerate with a lithic greywacke composition.
2. The dominant mode of the clast size distributions lies in the coarse pebble range varying from -4.14ϕ to -5.37ϕ (16–40 mm) with an average standard deviation of 1.77, indicating poor to very poor sorting.
3. Maximum clast size analysis suggests that in general variations tend to correlate to the mean grain size distribution as well as to the thickness variation.
4. No major change in clast sphericity values was found, as the composition of the source rocks was uniform throughout.
5. The clasts are subangular to subrounded. Measurements of clast roundness of a single lithology (-6ϕ to -7ϕ range) have shown medium to low average roundness (from .54 to .61). The degree of

roundness has linear relationship with the particle size as well as the conglomerate thicknesses.

6. Clast orientation patterns indicate an unimodal transport direction. The flow was predominantly from the southeast. This is similar to the direction of provenance for the sandstone (cross-bedding) above the conglomerate.

7. Results of the conglomerate analysis in the Zangu Mountain reveal that the bulk of the unit formed as a single alluvial fan deposit in an arid to semiarid region.

8. The rate of accumulation was approximately 48 cm/1000 years. Thus the alluvial fan in the Zangu Mountain was formed in a period of about 200,000 years.

CHAPTER 8

SUMMARY AND CONCLUSIONS

1. Lower Devonian sedimentary facies in Iran are coarse clastics — sandstones and conglomerates associated with evaporites. These facies indicate that nearshore marine to lagoonal depositional environments prevailed in northeast and central Iran, whereas much of the northwest was above sea level.
2. Middle Devonian rocks are more widespread through northern and central Iran. They consist mainly of carbonate and sandstone containing brachiopods, corals, conodonts and spores.
3. Upper Devonian marine environments extended from the north through central Iran south almost to Bandar Abbas. There is a marked decrease in the amount of clastic materials. Carbonate sediments containing brachiopods increased in the Late Devonian, suggesting a transgression over the greater part of Iran. The thickest and the most complete Devonian section occurs in the Tabas area, that is about 1870 m of clastic materials, evaporites and carbonates.
4. Three major facies regimes are recognised in the Devonian of the Kerman region. The Old Red Sandstone or continental and terrestrial facies, the alluvial fan deposits, and the nearshore facies including carbonate, clastic and reef deposits. Brachiopods, corals, spores and acritarchs dominate the fossils, but with minor amounts of bryozoans, crinoids and gastropods.
5. There is a marked similarity in the brachiopod communities from the Kerman region to those from northern and central Iran and western Afghanistan (see table 2.1). Nevertheless, Upper Devonian brachiopod species of Iran are different from those of Europe and North America described by many authors, e.g. Beus (1978), Biernat (1988), House (1975), McGhee and Sutton (1981, 1985). *Cyrtospirifer verneuili* has very wide range throughout Europe, North America, Iran and Afghanistan. The present writer raises the question of

whether it is a cosmopolitan species and/or whether it belongs to two individual subspecies.

6. The corals in Kerman, central and northern Iran are confined to the Frasnian formations. *Disphyllum* is a common genus throughout Iran and generally lived in shallow-water. Transgression in the Upper Devonian led to the progressive attenuation of reef complexes and to their near global termination before the close of the Frasnian stage (House, 1975). Famennian strata in Kerman are barren of corals but contain many large brachiopods, e.g. *Uchtospirifer*, suggesting a relatively deeper environment at this time.

7. The spore and acritarch taxa confirm the Frasnian stage defined by brachiopods and corals in the study area. The spores are more abundant within the shale beds in the Tizi section, northeast Kerman, than in the other sections. These floras together with higher quantity of clastic materials indicate that in general the source area was to the northeast (Lut block). The palynomorphs from the Frasnian successions in Kerman show identical characteristics to those from southern Iran, the Arabian Peninsula and Western Australia. Iran was thus apparently part of Gondwana during the Devonian period. Fragmentation became the dominant post-Palaeozoic pattern in Gondwanaland. It provided a source of additional crustal blocks, each with its own "biostratigraphic signature" (Gratsianova et al., 1988).

8. Results of the conglomerate analysis from Zangu Mountain suggest that the bulk of the unit formed as a single alluvial fan in an arid to semiarid region. This alluvial fan formed over a period of about 200,000 years. It shows similar characteristics to the Recent alluvial fans of Death Valley, California (Hooke, 1972). The proposed depositional model for this fan indicates that the source for the clastic materials was to the southeast. The flow direction and the source area are coincident with Devonian palaeogeography in Iran.

9. A shallow water, inner platform environment was inhabited by communities of the Spiriferida-Rhynchonellida-coral assemblages. These

communities are characteristically composed of an attached epifauna of brachiopods and corals. Occurrence of marine oolites, evaporites with rugose corals, suggests a subtropical environment during the Devonian here.

10. Similarity of lithofacies with identical brachiopods, corals and relatively small variation in the sedimentary thicknesses indicate that a very wide shallow marine environment prevailed throughout northern, central and southeast Iran in the Devonian period.

Although the present study provided much information on the stratigraphy of the Upper Devonian in Kerman, the base of the Frasnian and the top of the Famennian remain unknown. Further study of miospores and acritarchs will provide data for fixing stage boundaries.

Devonian sediments have been reported in many parts of Kerman (see geological map by Hückreide et al., 1962). A study of outcrops which have not been considered in the present research might confirm presence and/or absence of Lower and Middle Devonian in this area.

Crinoids, gastropods and bryozoans within the Devonian successions in the Hutk, Gerik and Shams Abad should be studied concerning their distribution, evolution and environmental significance.

The morphological characteristics of the brachiopods in Kerman are described but further studies of community assemblages in relation to environment, evolutionary patterns and the brachiopod zonal schemes are recommended.

Although the present writer failed to extract conodonts from the Devonian rocks in the study area, further sampling of the carbonates may provide data for conodont biostratigraphy.

A sedimentological, geochemical and mineralogical analysis of the Devonian sections in Iran for evidence such as iridium anomalies and the cause(s) of the Frasnian/Famennian mass extinction(s) is also suggested.

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